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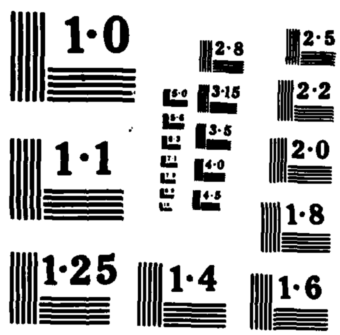
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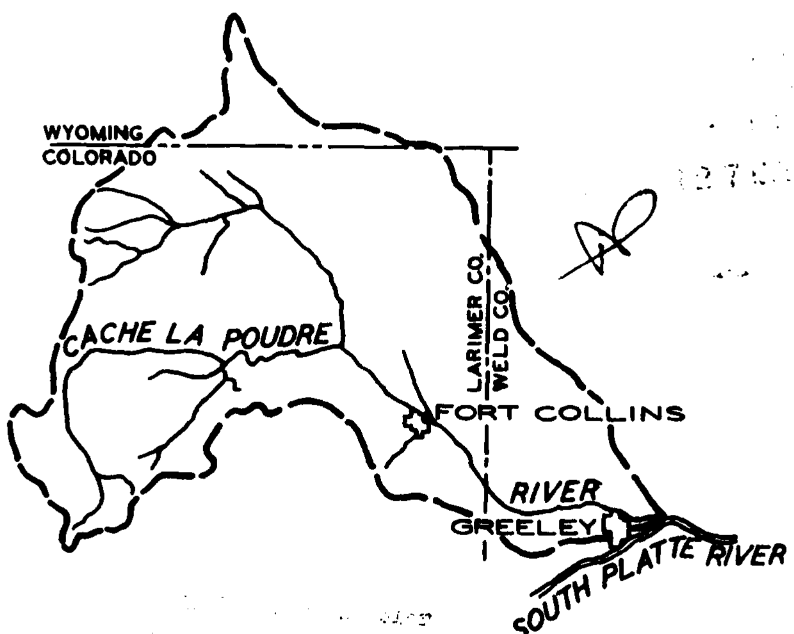
SPECIAL STUDY

OCTOBER 1981

(5)

CACHE LA POUDRE RIVER BASIN
LARIMER - WELD COUNTIES, COLORADO

VOLUME I
FLOOD HAZARD, DAM SAFETY AND FLOOD WARNING



US Army Corps of Engineers
Omaha District

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The Cache la Poudre River basin in Colorado is in a rapidly growing area. The population of Larimer and Weld Counties increased by about 60 percent between 1970 and 1980. The basin contains a number of flood hazard areas, from narrow canyon flood plains in the mountainous west to wide valley flood plains in the east. Local interests are concerned about the changine nature of the flood hazaros in the basin as a consequence of urban growth, particularly since the catastrophis Big Thompson River flood in the summer of 1976.

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SPECIAL STUDY
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES
COLORADO

VOLUME I
FLOOD HAZARD, DAM SAFETY, AND FLOOD WARNING

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October 1981

SPECIAL STUDY
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES
COLORADO

VOLUME I
FLOOD HAZARD, DAM SAFETY, AND FLOOD WARNING

Introduction

BACKGROUND

The Cache la Poudre River basin in Colorado is in a rapidly growing area. The population of Larimer and Weld Counties increased by about 60 percent between 1970 and 1980. The basin contains a number of flood hazard areas, from narrow canyon flood plains in the mountainous west to wide valley flood plains in the east. Local interests are concerned about the changing nature of the flood hazards in the basin as a consequence of urban growth, particularly since the catastrophic Big Thompson River flood in the summer of 1976. Discussions regarding a wide ranging study of the basin were initiated between the Omaha District, Corps of Engineers and local planners and elected officials in 1977 and a plan of study was agreed upon.

AUTHORITY

This study was made under continuing authority in Section 206 of the 1960 Flood Control Act, as amended.

PURPOSE

The purpose of this study was to analyze flood-related problems and provide information that will enable local governments to make decisions that will minimize or reduce flood hazards in the future.

SCOPE OF THE SPECIAL STUDY

The course of the study was primarily determined through coordination with the Omaha District, Colorado Water Conservation Board, Larimer County, Weld County, the city of Fort Collins, the city of Greeley, and the Larimer-Weld Regional Council of Governments. Numerous other agencies and private interests were also contacted during the study.

As the study progressed, tasks were deleted or added in consultation with local interests to respond to changes in identified needs or priorities. Since some work items were independent of other study tasks, the study results are presented in four separate volumes. Volume I considers basin flood hazards, dam safety, and flood warning. Volume II presents the detailed hydrologic analysis for the basin. Volumes III and IV present flood plain studies for Sheep Draw and Fossil Creek, respectively, which are two tributaries of the Cache la Poudre River lying in the path of current urbanization. All geographic locations referred to are in the state of Colorado unless otherwise indicated.

PURPOSE AND SCOPE OF VOLUME I

Volume I presents data on the flood problem including the characteristics of past and potential floods and discusses the development subject to flood hazards.

This volume also summarizes the dam inspection reports made under the National Dam Safety Program for dams in the Cache la Poudre River basin.

Alternative flash flood detection systems are formulated for the mountain portion of the Cache la Poudre River basin.

DESCRIPTION OF THE STUDY AREA

GEOGRAPHY

The Cache la Poudre River basin is located in north-central Colorado. A major left-bank tributary of the South Platte River, the Cache la Poudre River originates within Rocky Mountain National Park. It drains an area of 1,890 square miles, and flows about 121 miles from its origin to its confluence with the South Platte River about 5 miles east of Greeley. Except for a small area in Wyoming, almost all of the basin area is in Larimer and Weld Counties in Colorado. The basin is shown on plate 1.

The western portion of the basin lies within the southern Rocky Mountain Province of the Rocky Mountain system. Precambrian age rocks were uplifted and exposed throughout the Rockies. The eastern part of the basin lies within the Great Plains Province of the Interior Plains. Underlying the plains are sedimentary sandstones, shales, and limestone of cretaceous to tertiary age. During recent geologic time, stream erosion, glaciation, slope movement, and wind action produced flood plains, terraces, and the overlying mantle.

Most of the basin west of Fort Collins is mountainous. The drainage area at the point where the Cache la Poudre River emerges from the mountains is 1,055 square miles. This area is very rugged, featuring steep stream slopes and narrow valleys. Elevations in the mountains range from about 6000 feet to as high as 13,500 feet mean sea level (m.s.l.) Local relief often ranges from 500 to 1,500 feet. The plains east of the mountains are characterized by rolling hills interspersed with extensive areas of gently sloped plains. Elevations in the plains range from about 6000 feet m.s.l. at the foothills to about 4600 feet m.s.l. where the Cache la Poudre River joins the South Platte River.

The Cache la Poudre River basin has a continental type climate marked by wide ranges of temperature and irregular precipitation. Westerly winds dominate the climate for most of the year; this allows the Rocky Mountains to block atmospheric moisture originating from the Pacific Ocean. During the spring and early summer months, these westerly winds lose their predominance and moist air masses push up from the Gulf of Mexico. The plains portion of the study area receives about 75 percent of its precipitation during April to September.

The mountainous region of the basin has a rigorous climate with long winters, heavy snowfall, and a short growing season. For example, average annual snowfall at Estes Park is about 96 inches compared to 43 inches at Fort Collins. Temperatures are more moderate in the foothills than in either the mountains or the plains. Climatic characteristics of the plains are low humidity, warm summers, cold winters, light rainfall, and considerable year to year variations in precipitation.

Climatic data for Greeley in the plains, Fort Collins in the foothills, and Estes Park in the mountains are presented in table 1. Elevations for the three locations are 4648, 5025, and 7525 feet m.s.l., respectively. Precipitation in the mountains can be as much as 30 inches a year.

Most of the mountainous portion of the basin is forested and the greatest part of it is included within the Roosevelt National Forest. Forest occurs between elevations of 6000 to 7000 feet m.s.l. up to about 11,000 feet m.s.l. Ponderosa pine or lodgepole pine, Douglas fir, and quaking aspen are found at the lower elevations. Spruce-fir forests are found at the higher elevations. Alpine grasses and brush and barren or snow-covered areas occur above the timberline. Most of the basin's rangelands and almost all of the arable lands lie in the plains. Range and dry cropland typify the northern part of the plains, while irrigated cropland occupies the southern part.

Table 1
Climatic Data

City and County	Annual Mean Precipitation (inches)	Temperatures (degrees F) January Mean Maximum	January Mean Minimum	July Mean Maximum	July Mean Minimum
Estes Park, Larimer	15.9	37	15	78	46
Fort Collins, Larimer	14.9	40	12	84	54
Greeley, Weld	12.2	40	9	89	55

DEVELOPMENT AND ECONOMY

The Cache la Poudre River basin in the early days of settlem was crossed by Indians, trappers, miners, emigrants, and soldiers. During the 1860's and 1870's, agricultural "colonies" or cooperative land settlement organizations accelerated local growth. In the semiarid climate, only a limited number of cultivated crops could be grown without irrigation. Canal irrigation was quickly begun in order to assure good yields. The primary sources of water were the South Platte River and the Cache la Poudre River, which are fed by mountain snowmelt. Irrigation ditches and water storage reservoirs are now numerous in the plains.

By about 1900, surface water rights were fully appropriated. Transmountain diversion from across the Continental Divide was initiated to import water into the area east of the Rockies. The major diversion in this area is the Adams Tunnel of the Colorado-Big Thompson project which was constructed by the Bureau of Reclamation. The project began supplying water to parts of Larimer and Weld Counties about 1953 and has helped to stabilize crop production.

Droughts in the 1930's and 1950's accelerated the development of well irrigation. The primary aquifer is the South Platte River valley, but the Cache la Poudre River downstream from Fort Collins is also a significant ground water source.

Agriculture is a major economic activity in the basin. Principal irrigated crops are corn, sugar beets, beans, and alfalfa. Dry cropland produces winter wheat, barley, hay, or pasture in rotation. The rich irrigated farmland has placed the Fort Collins - Greeley area within the top 10 areas in the Nation for agricultural production. Agricultural related industries such as sugar beet processing, cattle feedlots, and packing houses are also important economic activities. Cattle feeding operations in Weld County make Greeley the major livestock market between Omaha, Nebraska, and the west coast.

In addition to agricultural industries, other area industries include electronics, photo supplies, dental appliances, plastic products, clothing, mobile homes, chemicals, cement, and lumber. Tourism is important in the mountain area. Another large employment sector is education. Colorado State University is located in Fort Collins and the University of Northern Colorado and Aims Community College are located in Greeley.

The known sources of metallic minerals and strippable coal beds lie outside the Cache la Poudre River basin. Minerals produced include stone, sand and gravel, petroleum and natural gas, lime, gypsum and mica.

The Larimer-Weld County area has a history of continued growth because of its strong economic base. Table 2 indicates population trends.

The flood reached Fort Collins late in the afternoon on 20 May and continued for about 3 hours, during which time about 150 houses in the lowlands were swept from their foundations. All bridges but one in Fort Collins were destroyed. Concerning Boxelder Creek the Greeley Tribune stated:

"The Boxelder, a small stream ordinarily only a few feet wide, was tearing down through a fertile valley filled from bluff to bluff with a sheet of water a mile wide, carrying buildings and bridges away in its mad rush."

Downstream from the mouth of Boxelder Creek, the floodwaters of the two streams reached a width of 1.5 miles in places.

The flood reached Greeley about 8:30 a.m. on 21 May, and flowed over a large area of the city. Downstream from the Union Pacific Railroad the lowlands were also flooded and the houses in that area were submerged to their window sills. The flood stage continued until noon, when the water fell almost as rapidly as it had risen.

Flood of June 1923. The flood of June 1923 was caused by a combination of melting snow and heavy rains. At the end of March, the snow cover was about 50 percent above normal. June was one of the wettest months on record.

Regarding the flood of 15 and 16 June, the Fort Collins Express, 16 June 1923, stated:

"Fed by mountain cloudbursts and heavy general rains, the (Cache la) Poudre River last night in 2 hours became a raging torrent. Cloudbursts, one at Livermore and another at a point not far away from there, late in the afternoon sent a wall of water down the canyon. At Laporte and Fort Collins the river rose 2 feet in as many hours."

Flood of May 1904. The flood of 20-21 May 1904 was caused by rains of cloudburst intensity on the North Fork Cache la Poudre River and Boxelder Creek watersheds at an altitude of about 7000 feet m.s.l.

J. A. Armstrong, irrigation engineer, investigated the flood on the North Fork Cache la Poudre River, and the following is abstracted from his report in USGS Water Supply Paper 147, published in 1905.

"The floods down these creeks were caused by a continuous heavy rain, or a succession of cloudbursts commencing before noon of the 20th and lasting 5 or 6 hours, centering about Stonewall Mountain at the head of Stonewall Creek. . . . Stonewall, Dale, and Lone Pine Creeks are all tributary to the North Fork Cache la Poudre River. The flood was down into Livermore, only a few miles, almost before anyone could remove anything out of the way, and had it been at night, there would probably have been great loss of life as well as property. The volume of water passing Livermore has been estimated at 20,000 cubic feet per second."

The flood reached the Cache la Poudre River early in the afternoon of 20 May and was augmented upstream from Fort Collins by floods from Dry Creek, Hook Canyon, and Moore Canyon. In describing the flood downstream from the canyon, the Greeley Tribune of 26 May stated:

"About the first warning of danger that people up the valley had was when a wall of water 10 to 14 feet high burst out of the Poudre Canyon (early in the afternoon), a couple of miles above Laporte. As quick as possible word was telephoned to Fort Collins of the coming flood, and the people of Laporte sought safety on high ground. When the water reached the open valley it spread over a surface of about a mile and its speed was somewhat slackened."

Flood of June 1891. The failure, 9 June 1891, of the wasteway at the Chambers Lake Reservoir on the headwaters of the Cache la Poudre River caused a severe flood on that river. According to the local newspaper, the break was apparently caused by increased melting of the mountain snow, due to the warm weather a few days before. This flood destroyed the recorder at the gaging station near the mouth of the canyon, hence no official record is available. The water commissioner, who was the observer, stated that the peak discharge was about 21,000 c.f.s. This estimate was evidently based on a high water mark.

The Fort Collins Courier, in its issue of 11 June 1891, gives the following account of this flood:

"About 4 p.m. June 9, the water superintendent was notified that a terrific flood was rushing down the (Cache la) Poudre canyon carrying everything before it.

"On came the mad, rushing torrent toward the plains, with deafening roar . . . bridges, fences, headgates, buildings, cattle, and horses were swept into the . . . flood.

"The island below the LaPorte bridge . . . was completely submerged, the water covering the floor of Mr. Nugent's house to a depth of 2 1/2 feet.

"The flood reached the railroad bridge north of the city (Fort Collins) about 5 p.m. . . . The bottomlands between the millrace and river were nearly all under water. The meadows and fields on the north and east side of the river were flooded.

"An eye witness of the flood as it broke through the Poudre canyon says the wall of water was fully 10 feet high and that logs and trees were tossed about like twigs."

Descriptions of selected floods are given to illustrate flood characteristics. Most of the historical flood narrative is taken from USGS Water Supply Paper 997 "Floods in Colorado" by Follansbee and Sawyer, 1948.

Flood of June 1864. An extra heavy snowpack augmented by a rainstorm on 9 June 1864 resulted in flooding on the Cache la Poudre River.

Historian Ansel Watrous wrote of the 1864 flood:

"Fort Collins . . . owes its origin and first place on the map to the intervention of a flood in the Cache la Poudre River. This flood occurred on the last days of May and first days of June 1864 and is said to have been the worst known by white men. The water . . . inundated the valley from bluff to bluff with a torrent that carried everything not firmly attached to the soil with it.

"It carried out the toll bridge at Laporte at a time when the movement of emigration westward was the heaviest and more than 200 emigrants were stalled on the bluffs south of Laporte . . . On the 9th of June, an extraordinary rainstorm set in on the watershed of the upper part of the river, melted the snow in the higher altitudes and an enormous volume of water laden with driftwood, poured into the already swollen channel, and the sullen roar of the rushing stream as it burst out of the canyon was heard for a long distance. On reaching the plains, the water spread out and submerged the bottom lands from bluff to bluff to a depth of several feet. The storm occurred in the afternoon and the raging torrent . . . swept down through the soldiers' camp (at Laporte) in the night almost without warning . . . the campgrounds were completely submerged and only the roofs of the cabins . . . were visible . . . Fortunately, no lives were lost, but there were several narrow escapes by the settlers on the bottom lands."

Floods occurred on various parts of Eaton Draw in 1935, 1951, 1954, 1961, 1965, 1972, and 1974. A major flood occurred on 1 May 1977.

Storms in the Ault and Eaton area caused flooding along Lone Tree Creek in June 1973. Many farms were inundated and the Eaton Sewage Plant was damaged.

Available damage data for historic floods is summarized in table 5. Damages are given in terms of price levels at the time of the flood. With increasing development and inflation, a moderate flood may now produce more dollar damage than a major flood of earlier years.

Table 5
Historic Flood Damage Estimates
Cache La Poudre River Basin

Date	Stream	Location or Type of Damage	Damage
1904	Cache la Poudre	Crops and livestock	$ 33,000
		Farm improvements & machinery	30,000
		Irrigation structures	35,000
		Road & railroad structures	67,000
		Laporte	5,000
		Fort Collins	10,650
		Greeley	1,000
		Total 1904 flood	$ 181,650
1904	North Fork	Livermore	2,000
1917	Cache la Poudre	Greeley and vicinity	19,000
1923	Cache la Poudre	Basin	132,000
1923	North Fork	Livermore	500
1947	Cache la Poudre	Main stem	74,000
1949	Cache la Poudre	Main stem	20,000
1951	Cache la Poudre	Main stem	96,900
	Dry Creek	Undetermined	76,300
	Small draw	Colorado State College	270,000
		Total 1951 flood	$ 443,200
1965	Cache la Poudre	Greeley	85,000
		Rural areas	711,000
		Transportation facilities	1,915,000
		Total 1965 flood	$2,711,000

Table 4
Peak Discharges for Historical Floods
Cache La Poudre River[1/]

Date	Peak Discharge at USGS Gaging Station Upstream from Fort Collins c.f.s.	Date	Peak Discharge at USGS Gaging Station Downstream from Greeley c.f.s.
22 Jun 1883	7,900		
20 May 1884	6,850		
9 Jun 1891	21,000[2/]		
29 May 1900	5,000		
21 May 1901	12,000		
9 Jun 1903	4,100	11 Jun 1903	2,820
20 May 1904	[3/]		
19 Jun 1909	5,900	[4/]	
2 Jun 1914	5,380		
23 Jun 1917	7,000	24, 26 Jun 1917	4,220
20 Jun 1918	5,200	[4/]	
8 Jun 1921	5,230		
15 Jun 1923	8,550	17 Jun 1923	[5/]
14 Jun 1924	7,440	14 Jun 1924	2,780
31 May 1930	10,200	1 Jun 1930	1,270
22 Jun 1938	6,180	4 Sep 1938	1,230
2 Jun 1943	3,380	7 May 1943	2,190
22 Jun 1947	4,660	23 Jun 1947	4,050
5 Jun 1949	6,090	15 Jun 1949	2,780
3 Aug 1951	4,630	5 Aug 1951	3,760
29 May 1958	3,770	30 May 1958	2,230
10 Jun 1961	2,960	11 Jun 1961	2,870
11 Jun 1965	4,810	19 Jun 1965	3,480
23 Jun 1967	2,210	24 Jun 1967	2,050
14 Jun 1973	3,780	16 Jun 1973	2,360
31 Jun 1976	7,340	2 Aug 1976	1,600
16 Jun 1978	3,740	12 Jun 1978	2,130

1/ From USGS stream gaging records in excess of 5,000 c.f.s. at the gage upstream from Fort Collins or 2,000 c.f.s. at the gage downstream from Greeley.

2/ Caused by failure of Chambers Lake Dam.

3/ Greater than 1891 flood.

4/ Gaging record is not continuous.

5/ Discharge unavailable.

FLOOD HISTORY

This section presents general data on past floods and descriptions of selected floods to show the nature of the flood problem.

CACHE LA POUDRE RIVER BASIN

Stream capacities on the Cache la Poudre River range from about 5,000 cubic feet per second (c.f.s.) near Fort Collins to about 3,000 c.f.s. at Greeley. Streamflow records from the U.S. Geological Survey (USGS) gaging stations on the Cache la Poudre River upstream from Fort Collins and downstream from Greeley, supplemented by data collected by the Colorado State Engineer, indicate that 27 floods of varying severity have occurred since 1882 in the vicinity of either Fort Collins or Greeley, or both. In addition, major floods on the main stem are known to have occurred in June 1844, June 1864, and May 1876; however, peak discharge estimates for these floods are not available. Peak discharges for historical floods since 1882 are shown in table 4.

In addition to floods on the main stem, it is known that flooding occurred due to runoff from small canyons in the Fort Collins area during 1 through 4 September 1938. High discharges occurred on 31 July 1976 on some minor tributaries in the foothills region of the Cache la Poudre River basin because of heavy rainfall that caused the Big Thompson River flood. Localized flash flooding occurred in Larimer and Weld Counties on 24 and 25 July 1977 due to heavy thunderstorm rainfall.

Local streamflow records extending back to 1904 were obtained by the Soil Conservation Service during its studies of the Boxelder Creek watershed. These records indicate that some flooding occurs in the watershed every 2 years on the average and that large floods occurred on Boxelder Creek in 1904, 1909, 1922, 1930, 1933, 1937, 1941, 1947, 1961, 1963, 1965, 1967, and 1969. In May and June 1976, two storms caused $46,100 in damage and took four lives in the Wellington vicinity.

The city of Fort Collins has a special ordinance which requires regulation of flood plain land use. Fort Collins also has an ongoing program for acquiring flood plain lands for public use activities such as parks and recreation fields.

Larimer County has enacted flood plain regulations to supplement its zoning ordinance. The regulation defines allowable land uses in a "Floodway District" and a "Flood Fringe District." Structures for human habitation are prohibited in the "Floodway District." All structures constructed in the "Flood Fringe District" must be above the regulatory flood elevation.

Weld County flood plain land use regulations include different restrictions for a defined "floodway", "low hazard district", and "flood prone tracts". Structures are not allowed in the "floodway" but may be constructed in the "low hazard district" with special restrictions. Special studies are required by the developer of "flood prone tracts" to identify hazards the development may impose. County subdivision regulations require the construction of detention ponds in areas of new development to assure that development will not increase runoff.

FLOOD FIGHTING AND EMERGENCY EVACUATION

Emergency actions in the event of a flood in the study reach are coordinated through the Civil Defense offices in Larimer County and in Weld County. These offices coordinate general disaster activities.

The Denver Weather Service Forecast Office (WSFO) of the National Weather Service (NWS), under the National Oceanic and Atmospheric Administration (NOAA), provides general flash-flood warnings.

Halligan Reservoir, built on the North Fork Cache la Poudre River, has attenuation effects downstream. Although the reservoir does not have specific flood control storage, floodflows are delayed by their passage through the reservoir spillway and are, thus, reduced.

On the plains, the cumulative incidental flood control effects of reservoirs can be significant as water is diverted from streams to fill storage in the reservoirs. Peak discharges on the Cache la Poudre River are attenuated considerably by these diversions. Peak discharges are also attenuated by valley storage. Discharges are reduced as floods spread out to fill the broad Cache la Poudre River Valley. On the smaller tributaries, diversion dams or canals may absorb normal high flows and result in complacency about flooding.

Under the provisions of the Watershed Protection and Flood Prevention Act, Public Law 566, a Soil Conservation Service watershed project for Boxelder Creek is under construction. The project includes land treatment measures together with construction of five single-purpose floodwater-retarding structures and one grade-stabilization structure. The Soil Conservation Service estimates that the project may reduce floodwater damages in the watershed by $171,310 annually.

REGULATION

Flood plain land use within the city limits of Greeley and Fort Collins is regulated by the respective city. All other flood plain land use is regulated by Larimer or Weld County.

The city of Greeley adopted a zoning ordinance in July 1976 which requires construction of detention ponds in new subdivisions designed to assure that development of the subdivision will not increase runoff. The city, however, has not enacted flood plain ordinances sufficient to be included in the National Flood Insurance Program as of this report.

Table 3 (Cont'd)
Summary of Flood-Related Studies
Cache La Poudre River Basin

Federal Insurance Administration

Locality	Type of Study	Date Effective
Wellington (Boxelder Creek and Coal Creek)	Flood Insurance Rate Map	15 February 1979
Larimer County (unincorporated areas)	Flood Boundary and Floodway Map	2 April 1979
Larimer County (unincorporated areas)	Flood Insurance Rate Map	2 April 1979
Fort Collins (Cache la Poudre River and Spring Creek)	Flood Boundary and Floodway Map	16 July 1979
Fort Collins (Cache la Poudre River and Spring Creek)	Flood Insurance Rate Map	16 July 1979
Greeley (Cache la Poudre River)	Flood Boundary and Floodway Map	16 July 1979
Greeley (Cache la Poudre River)	Flood Insurance Rate Map	16 July 1979
Weld County (unincorporated areas)	Flood Boundary and Floodway Map	18 March 1980
Weld County (unincorporated areas)	Flood Insurance Rate Map	18 March 1980
Eaton (Eaton Draw)	Flood Insurance Rate Map	4 June 1980

Soil Conservation Service

Location	Type of Study	Result	Date Completed
Boxelder Creek Basin	P.L. 566 Watershed Work Plan	Recommended land treatment and some structures	Authorized April 1974
Boxelder Creek	Flood Plain Information Report	Lower end of creek to be regulated as flood prone area	May 1970

Table 3 (Cont'd)
Summary of Flood-Related Studies
Cache La Poudre River Basin

Corps of Engineers (Cont'd)

SECTION 14 STUDIES

Year Initiated	Year Ended	Location	Stream	Most Feasible Alternative	Recommendation
1976	1976	Fort Collins	Cache La Poudre River	Bank protection	Construction recommen:

FLOOD PLAIN INFORMATION REPORTS

Locality	Sponsoring Agency	Date Completed
Cache la Poudre River at Fort Collins	City of Fort Collins, Larimer County	October 1973
Cache la Poudre River at Greeley	City of Greeley, Weld County	March 1974
Cache la Poudre River, Fort Collins to Greeley	Larimer and Weld Counties	October 1975

SPECIAL STUDIES

Locality	Sponsoring Agency	Date Completed
Cache la Poudre River at Poudre Park	Colorado Water Conservation Board	December 1978
"The Slough" at Severance	Colorado Water Conservation Board	June 1979

DAM INSPECTION REPORTS

See section on "Dam Safety" in this volume.

Table 3
Summary Of Flood-Related Studies
Cache La Poudre River Basin

Corps of Engineers

SURVEY REPORTS

Year Completed	Published	Location	Most Feasible Alternative	Recommendation
1945	House Document No. 669 80th Congress 2nd Session	South Platte River Basin	None. Analyzed historic flood damages	No projects recommended in Cache la Poudre River basin
1977	Review Report for Water and Related Land Resources Management Study	Metropolitan Denver and South River and Tributaries	Range of alternatives for water supply, quality, flood control	Special Study for Cache la Poudre River Basin

PRELIMINARY EXAMINATION REPORTS

Year Completed	Location	Most Feasible Alternative	Recommendation
1948	Greeley	Levee and Channel improvements at Greeley	Recommended survey report at Greeley (Further studies not conduct

SECTION 205 STUDIES

Year Initiated	Year Ended	Location	Stream	Most Feasible Alternative	Recommendation
1961	1963	Greeley	Sidehill Runoff	Small Dams	Infeasible
1966	1969	Fort Collins	Spring Creek	Channel Improvements	Infeasible

PRIOR STUDIES

A number of flood control and flood plain management studies of various kinds have been published by different agencies for the Cache la Poudre River basin. Table 3 lists these studies in brief summary form.

In addition to the Corps of Engineers other Federal agencies involved in flood plain management activities include the Federal Insurance Administration, under the Federal Emergency Management Agency, and the Soil Conservation Service.

Survey reports study a wide range of water resources problems. Section 205 and Section 14 reports involve small projects for flood control or streambank protection. The special studies are flood plain information studies done under the Corps' Technical Assistance Program.

Other reports have been prepared by private consultants, local governments, or universities.

FLOOD DAMAGE REDUCTION MEASURES

PHYSICAL IMPROVEMENTS

The Cache la Poudre River basin is laced with a complex system of diversions, canals, and reservoirs. There are about 70 reservoirs of varying sizes, most in the plains region. Except for two large reservoirs on the North Fork Cache la Poudre River, storage reservoirs are generally located on small tributaries or offstream and have little individual effect on decreasing floodflows. Almost all reservoirs in the basin are for irrigation or water supply; the exceptions are the SCS dams on Boxelder Creek which were designed for flood control. The operation of the reservoirs results in their being nearly full about June, and there is little extra storage available during the flood season.

Table 2
Population in Selected Areas

Year	Fort Collins	Greeley	Larimer County	Weld County
1930	11,489	12,203	33,137	65,097
1940	12,251	15,995	35,539	63,747
1950	14,937	20,354	43,554	67,504
1960	25,027	26,314	43,343	72,344
1970	43,337	38,902	89,900	80,297
1980(prelim)	66,235	52,480	149,205	122,905

Fort Collins in Larimer County and Greeley in Weld County are the two largest communities. Each city contains over 50 percent of the manufacturing and retailing activities in its respective county. Another community, Windsor, lies between these two cities. Industrial development near Windsor in 1970 spurred an increase in the town's population from 1,600 in 1970 to about 4,300 in 1980. The mountain area is sparsely populated, although several recent subdivisions around Red Feather Lakes have attracted new residents.

Flood Hazard

GENERAL

This section describes the existing flood hazard situation. The flood history, prior studies, and flood control measures are presented. Because previous reports on the flood hazard in the plains area have been made the detailed discussion in this report emphasizes the Cache la Poudre River canyon area in the mountains.

In its issue of 17 June 1923, the Fort Collins Express published a dispatch from Greeley which read:

"High water on the (Cache la) Poudre second only to the flood of 1904, tonight shut off all travel on highways north and west of the city and had driven a score of families from their homes on the lowlands. The south channel of the (Cache la) Poudre is within a few inches of the Union Pacific track between here and Cheyenne. Three feet of water has driven tourists from their camp ground in the bottoms. The Boyd farm northwest of here was entirely under water for the first time since 1884."

Flood of May - June 1930. Heavy rains in the North Fork Cache la Poudre River Basin on 31 May 1930 caused the highest flood on the North Fork since 1904 and a flood on the Cache la Poudre River at the canyon gaging station that ranked among the most severe floods in that area.

The storm that caused the flood appeared to originate in the foothills southwest of Livermore, where the altitude ranges from 7000 to 7500 feet m.s.l. It traveled northwest, releasing heavy precipitation about 7 miles northwest of Livermore, and ended in a hailstorm that covered the ground with hail to a depth of several inches. At Livermore the rain started at 3 p.m. and continued until 6 p.m., with the heaviest fall about 5 p.m. No record of the amount of precipitation is available. The North Fork Cache la Poudre River started to rise about 5 p.m. and reached its peak an hour later on the Livermore gage. The river remained high until 8 p.m., then dropped rapidly. The peak discharge was 6,800 c.f.s., as determined by a slope-area measurement. A small area at Livermore was inundated.

Between Livermore and the canyon gaging station on the Cache la Poudre River about 14 miles downstream, the flood traversed a narrow

valley and terminated in a canyon with little or no channel storage. The flood reached the canyon station at 8:15 p.m., on 30 May and destroyed the gage recorder, but from high water marks the peak discharge was estimated at 10,200 c.f.s. The Fort Collins Express-Courier, 1 June 1930, states that the storm, which extended into the upper basin of the Cache la Poudre River, was not sufficient to increase materially the flow upstream from the mouth of the North Fork. That flow was about 2,000 c.f.s., indicating that the flood peak on the North Fork was about 8,000 c.f.s. No definite information regarding the duration of the flood is available, but the flood reached Fort Collins, 12 miles downstream, about 10 p.m. and lasted only 2 hours. The chief damage of the flood was wrought on bridges, highways, and irrigation canal head gates upstream from Fort Collins. The river, although bankfull, did not overflow its channel in Fort Collins.

<u>Flood of August 1951</u>. During the afternoon and night of 3 August 1951, a heavy rainstorm occurred over the front range and foothills from Boulder to Fort Collins. Approximately 12 inches of rainfall occurred near Bellvue. A severe flood resulted on the Cache la Poudre River and on its tributary Dry Creek. The flood peak on the Cache la Poudre River at a point 4 miles upstream from the mouth of Dry Creek occurred at 9:50 p.m. on 3 August at an estimated 4,910 c.f.s. discharge. A peak of 12,000 c.f.s. was estimated at Laporte, about 2 miles downstream from the confluence with Dry Creek. A crest of 3,700 c.f.s. was reached at 3 p.m. on 5 August at Greeley.

On the main stem, large areas of cropland were inundated as well as numerous houses and farm buildings. Damage resulted to numerous irrigation dams, headworks, and canals. At Fort Collins, runoff from a small draw flooded a portion of Colorado State College and a 10-block area of Fort Collins.

The flood on Dry Creek washed away or seriously damaged nearly everything in its path. Three lives were lost. Dry Creek eroded new and wider channels in many places and caused considerable loss of land.

1976 BIG THOMPSON RIVER FLOOD

The Big Thompson River basin is adjacent to and south of the Cache la Poudre River basin. This historic flood serves as an indication of flood problems in the mountain area of the Cache la Poudre River basin.

Atmospheric conditions on 31 July 1976 combined to feed a heavy inflow of moist air into the Front Range area of Colorado. This created unstable conditions unusually favorable for thunderstorms.

Saturday, 31 July 1976, was the beginning of a 3-day weekend to celebrate Colorado's centennial. In the 20-mile long Big Thompson Canyon, there were as many as 2,500 visitors and permanent residents of all ages. Between 5:30 p.m. and 6 p.m., a light rain began in the Estes Park area, in the upstream part of the canyon. An explosive thunderstorm developed, with thunderheads ranging up to 62,000 feet stalling instead of moving across the area as they usually do. Torrential rains estimated at up to 12 inches in 4 hours fell in the part of the basin between Estes Park and Drake.

Between 6 p.m. and 8 p.m., travelers were encountering rain of increasing intensity. The first warnings of an imminent disaster came from telephone reports of torrential rains, rising water, and washouts along U.S. Highway 34 by people who were experiencing difficulties in the canyon. Early in the flood period, both ends of the highway escape route were destroyed and it became a death trap for frantic motorists.

At approximately 8:25 p.m., calls reporting flooding and requesting aid started the chain of events which would result in the effort to warn people about the flash flood.

Ironically, there was no rain in the lower end of the canyon. All the water came from upstream areas. This added an element of disbelief to warnings. At 9 p.m., the Loveland Police dispatcher received a message from the State Patrol requesting a warning from Drake down the canyon. The dispatcher followed the wave of water down the canyon by the telephone lines that went dead in the water's path as she was calling to warn people. Water swept boulders, trees, vehicles, houses, and foundations away and left the ruins strewn downstream. Shortly after warnings were given by the State Patrol, the flood passed through Drake and left devastation and death in its wake. Approximately 17.5 miles downstream from Estes Park, Cedar Cove was then engulfed and by 9:45 p.m., the flood hit the area west of Loveland. The floodwaters ran unchecked for nearly 5 hours. At 10:45 p.m., the Water and Power Resources Service's 227,000-pound siphon at the mouth of the Narrows collapsed when a floating building hit the southern support.

Within 4 hours or so, the worst of the rainfall was over and the peak flow had reached the mouth of the canyon. In the Narrows area at the mouth of the canyon, it is estimated that, at peak flow, the velocity of the water was on the order of 15 miles per hour. The frequency of the peak at the canyon mouth has been variously estimated at from 300 years to 750 years.[4] At the mouth of the Big Thompson canyon, the flow increased from the normal rate of 200 c.f.s. to about 31,200 c.f.s. Water levels in the canyon reached from 10 to 30 feet above normal.[18] The rainfall covered a relatively small area. An estimated 70 square miles of the total 304 square mile drainage area at the canyon mouth contributed to the flood peak.

Damage was severe, not only because of the great flow of water, but also because of debris. Even when flow did not wash away a building, it was severly damaged by flooding, by rocks slamming into

walls, and by a deposit of sediment inside. Erosion caused considerable damage to U.S. Highway 34. The worst damage occurred on the outside of small-radius curves. Automobiles parked on road sections that were straight or elevated above the flood often escaped damage, however, as the road was not washed away.[3]

The effect of the flash flood was minimal beyond Loveland. Damages were estimated at over $35,000,000, most of which were to highways or private buildings. A county survey indicated that 252 structures were damaged more than 50 percent.

Many reports state that there was an approximate 45-minute warning to residents; other reports state that some people received no warning. The tragedy lies in the fact that many warnings were not heeded. Many people decided to remain in what seemed to be a secure situation rather than venture out in a dark, roaring storm, or they decided to stay where they were because they saw no rain. A total of 139 bodies were recovered and 6 have been declared missing.

FLOOD CHARACTERISTICS

HYDROLOGIC CHARACTERISTICS

Storm Types. Three general types of storms occur in this region. Most severe storms usually occur during the spring and summer with May and June having the greatest frequency of occurrence. Eighty percent or more of the annual precipitation falls during the growing season from March through September.

Most of the major storms have been caused by a pressure system which involves a high pressure area to the north of the region and a low pressure area to the south. As a result, a moist air mass from the Gulf of Mexico is carried westward across the basin and into the eastward face of the Front Ranges. Heavy precipitation results over the mountains from the moist air being lifted up the mountain slopes.

The frontal-type storm occurs when a cold air mass moves into the region from the north at the same time that moist air is transported into the region by a low pressure system south of the region. The moist air is lifted along the cold front and curved westward under the influence of the low pressure cell to the south. Precipitation becomes general behind the cold front.

Cloudbursts, due to daily temperature variations, occur during the summer in the mountain regions and over the plains area within about 75 miles of the foothills. The morning sun results in greater heating over the mountains than over the plains. A flow of air up the mountain slopes soon originates. Thunderheads form over the mountains. The thunderstorms, which begin about noon in the mountains, move in a northeastward direction and are dissipated over the plains. The intensities of the thunderstorms are influenced by the volume of moist unstable air in the region.

Most floods along the Cache la Poudre River have been caused by rainfall adding to snowmelt in the month of June. It is possible, however, for severe flooding to occur from rainfall alone -- as evidenced by the disastrous Big Thompson River flood.

Discharge-Probability Relationships. The discharges of floods of selected probabilities are listed in table 6. The 100- and 500-year flood discharges at selected locations are displayed on plate 2.

The hydrologic studies used to derive the discharges are presented in Volume II. Discharges in the mountains were determined by use of the Massachusetts Institute of Technology Catchment (MITCAT) Model. Discharges in the plains were determined by synthetic unit hydrographs. From the flood history and from table 6 and plate 2, the attenuation of peak discharges as floodwaters leave the mountains and cross the plains is evident. In this analysis, attenuation results from valley storage.

The flood discharge is reduced as the floodwaters spread out to fill the broad valley. Irrigation diversions from the Cache la Poudre River were not included in the analysis. Halligan Reservoir, on the North Fork Cache la Poudre River, also reduces flood peaks as they pass through its spillway.

Table 6
Potential Flood Peak Discharges
Cache La Poudre River Basin

Stream and Discharge Location	Drainage Area (sq. mi.)	10-year (c.f.s.)	100-year (c.f.s.)	500-year (c.f.s.)
North Fork Cache la Poudre River				
Upstream from Halligan Dam	354	3,440	14,980	32,120
Downstream from Halligan Dam		1,980	9,260	22,790
Upstream from Lone Pine Creek	445	2,020	9,800	22,950
Downstream from Lone Pine Creek	532	2,510	12,170	27,970
At Mouth	566	2,490	11,830	26,940
Lone Pine Creek				
At Mouth	87	1,260	4,810	9,510
Cache la Poudre River				
Upstream from Poudre Park	385	4,960	16,300	31,870
Downstream from Poudre Park	409	5,170	17,320	36,220
Upstream from confluence with North Fork	422	5,230	17,700	37,040
At Bluff line	1,055	7,000	17,400	31,000
Upstream from Dry Creek	1,102	8,400	16,200	23,800
Downstream from Dry Creek	1,195	10,100	19,700	28,200
Upstream from Boxelder Creek	1,245	8,000	16,600	24,000
Downstream from Boxelder Creek	1,537	17,700	28,500	42,000
Upstream from Eaton Draw	1,825	2,680	8,100	14,600
Downstream from Eaton Draw	1,875	3,550	10,700	19,000
At Mouth	1,890	3,100	9,400	16,800

Flood Peaking Time. In addition to factors such as flow depth and velocity, the peaking time of flood runoff affects the nature of the flood hazard; the peaking time of flood runoff is the time from the runoff-producing rainfall to the time the flood reaches its maximum discharge. Also peaking time is generally related to duration. It would be expected that a rapidly rising stream would have a rapid fall and a short duration of flooding. Table 7 indicates the peaking time of floods from mountain rainstorms at various locations in the basin. It also indicates the time from the start of rainfall runoff to other flood events pertinent to flood warning.

Peaking times in the mountains were obtained by the MITCAT model. Peaking times in the plains were developed in the following manner. The peaking time of the main stem near the confluence with the North Fork of the Cache la Poudre River is taken as a starting point. This was developed by the MITCAT model. Downstream from the confluence, the MITCAT model was not used. A synthetic flood hydrograph for the 100-year flood was routed downstream. The time at which this hydrograph reached various points downstream was noted. This was added to the peaking time of the main stem flood near the edge of the mountains (the confluence with the North Fork) to obtain the total peaking time. Floods were assumed to originate from the main stem as North Fork floods are slower.

The peaking time of flood runoff is more graphically illustrated on Plate 3. At the extreme lower end of the basin, peaks can occur in 1 day or more. In the mountains, minor tributaries may have only an hour or less from rainfall runoff to flood peak.

PHYSICAL CHARACTERISTICS

Stream and Valley Characteristics. The slope of the Cache la Poudre River averages from 3 to 10 feet per mile across the plains. The depth of the Cache la Poudre River channel in the plains ranges from approximately 5 to 14 feet with the average being about 10 feet.

Table 7
Timing of Mountain Flood Runoff(1)
Cache La Poudre River Basin

Stream and Location	Time Interval (Hours): Rainfall to Flood Peak(2)	Rainfall to Significant Flooding(3)	First Rise to Significant Flooding(4)
North Fork Cache la Poudre River			
Above Halligan Reservoir	3 3/4	2 1/4	3/4
Below Halligan Reservoir	6 1/4	4	1 1/4
Below Lone Pine Creek	6 1/4	3	2
Mouth	7 3/4	4 1/4	1 1/2
Lone Pine Creek			
Mouth	3 3/4	2 1/4	3/4
Cache la Poudre River			
Poudre Park	3 1/4	1 1/2	3/4
Canyon Mouth	3 3/4	2	3/4
Near Laporte	5	3	3/4
Fort Collins	7 3/4	4 1/4	1
Larimer-Weld County Line	15 1/2	11 3/4	4

(1) The flood in the plains is assumed to originate from the main stem in the mountains, which has more rapid runoff than the North Fork watershed. No rainfall was assumed over the plains. The 100-year flood was used in the timing analysis, but other floods would not differ materially.

(2) Time from 15 minutes after start of heavy rainfall to peak discharge.

(3) Time from 15 minutes after start of heavy rainfall to threshold of significant flooding (defined as 5,000 c.f.s. on major streams and 2,500 c.f.s. on major tributaries).

(4) Time from noticeable rise in streamflow (defined as 1000 c.f.s. on major streams and 500 c.f.s. on major tributaries) at the designated location to threshold of significant flooding.

The channel top width varies from about 60 feet to 160 feet. In the vicinity of Fort Collins, the channel gradient varies from 28 feet per mile to 16 feet per mile and the channel averages 160 feet wide and 7 feet deep.

In the mountains, from Spencer Heights to the canyon mouth, the Cache la Poudre River generally slopes about 60 feet per mile. The channel is about 100 feet wide and is flat-bottomed with steep banks generally 5 to 15 feet high or sometimes higher. The bed material is usually coarse, ranging from gravel to boulders. Upstream from Spencer Heights, slopes reach 100 feet per mile on the main stem. On the North Fork Cache la Poudre River, stream gradients are about 28 feet per mile from the mouth to Livermore and 60 feet per mile from the vicinity of Livermore to Halligan Reservoir.

The Cache la Poudre River valley ranges from about 0.5 mile to 1.5 miles wide in the plains. From the canyon mouth to Spencer Heights, the valley is narrow and ranges from about 200 to 1,500 feet in width. Upstream from Spencer Heights, the valley narrows to as little as 100 feet. The Cache la Poudre River valley in the mountains is bordered by steep bluffs several hundred feet high. The valley of the North Fork is generally only a few hundred feet wide downstream from Halligan Reservoir, although it widens to about 1 mile in the vicinity of Livermore.

Flood Plain Widths. In the plains, the Cache la Poudre River flood plain ranges from about 3,000 to 6,000 feet in width; it narrows upstream from Fort Collins to 500 feet near the canyon mouth. In the mountains the flood plain is only a few hundred feet in width.

The flood plain of Boxelder Creek, the largest tributary in the plains area of the basin, is several hundred feet wide along the upper reaches and over 3,000 feet wide from Wellington to the confluence with

the Cache la Poudre River just downstream from Fort Collins. Other tributary flood plains in the plains region are substantially narrower. The flood plains of Sheep Draw and Fossil Creek, for example, average a few hundred feet wide or less.

Flood Depths and Velocities. Detailed flood plain studies completed prior to this study are available only for the Cache la Poudre River in the plains and for the Poudre Park area in the mountains. Available information indicates major floods in the plains reaches would range from 8 to 15 feet deep above the channel bed. Channel velocities range from 2 to 5 feet per second. Depths on the overbank are generally 5 feet or less, although occasionally deeper. Overbank velocities are generally about 1 to 2 feet per second, but velocities could be higher at certain points.

In the narrow mountain canyon at Poudre Park, the 100-year flood averages about 15 feet deep above the streambed and the 500-year flood averages about 20 feet deep. Channel velocities can be 15 to 20 feet per second or greater with overbank velocities of about 5 to 10 feet per second. In general, floodwater 2 or more feet deep and flowing at a velocity of 3 or more feet per second could easily sweep adults from their feet, thus creating definite danger of injury or drowning.

FLOOD HAZARD POTENTIAL

This section presents information on the development that is subject to flood hazards.

PLAINS REGION

In the plains section of the basin, most of the flood plain lands are used for irrigated or dry cropland, pasture, or rangeland. There is, however, some sand and gravel mining and there are numerous highway and railroad structures. Portions of several urban areas are also located within these flood plains. Along the main stem, these include

Bellvue and Laporte, (each of which had a population of less than 1,000 in 1970), Fort Collins, and Greeley. The 100-year flood plain of the Cache la Poudre River from the canyon mouth to the South Platte River covers about 12,700 acres. Most of the town of Wellington, with an estimated population of 691 in 1980, lies within the flood plain of Boxelder Creek.

Adjacent to Greeley the flood plain is moderately developed; it contains farms, pasture, feedlots, gravel pits, and commercial and residential development. A large number of buildings are located in the flood plain on the northeast side of Greeley. In addition, railroads, state and local roads, and public utilities are subject to flooding.

In the Fort Collins area, development is generally limited to Laporte, to an area at the U.S. Highway 287 crossing north of Fort Collins and to an area near the Colorado Highway 14 crossing east of the city.

A detailed flood damage analysis was made for the communities of LaPorte, Fort Collins, and Greeley. Table 8 summarizes data on the flood hazard potential at these urban areas. Damages are for buildings and contents and do not include damages to streets and utilities or emergency and cleanup costs. Price levels are indexed to September 1980.

The rapid development of land around Fort Collins and Greeley may result in new flood hazard areas. Specific areas of concern include the Spring Creek and Fossil Creek flood plains near Fort Collins, the flood plain of Sheep Draw near Greeley, and the rather undefined flood plain of the watershed near the city of Windsor.

Table 8
Urban Flood Plain Development
And Damage Potential
($1,000)

Item	Community: LaPorte	Fort Collins	Greeley
Value of Development			
Residential	$12,282	$14,337	$11,889
Commercial	1,859	18,132	10,507
Industrial	196	8,762	7,676
Other	--	1,001	212
Total	$14,337	$42,232	$30,284
Damages by 100-yr Flood	1,092	9,304	4,676
Average Annual Flood Damage	90.1	655.7	112.8

The entire Cache la Poudre River flood plain is a source of high quality gravel. Changes in flood plain characteristics resulting from this mining may affect the potential flood damages; this will depend upon how the gravel is mined and the condition of the flood plain when the mines are abandoned.

MOUNTAIN REGION

Flood plains in the mountains are generally undeveloped except along the main stem of the Cache la Poudre River. The flood hazard is characterized by narrow flood plains that have experienced scattered encroachments. Several small resort communities, campgrounds, and picnic areas serve tourists. Permanent or vacation homes are located in these communities, or are scattered in isolated developments along the valley bottom. The river is known as a good trout fishing stream and kayaking is popular in high water along the lower reaches of the canyon during June. Most of the land along the river is managed by the U.S. Forest Service. Private land is generally restricted to a narrow strip along the bottom land. Colorado Highway 14 parallels the Cache la Poudre River from the canyon mouth to a point upstream from Spencer Heights.

Plate 4 indicates the location of Plates 5 through 11 which show areas of population concentration likely to be subject to flood hazards in the Cache la Poudre River canyon. The flood hazard, of course, would extend along the entire length of the river. No detailed flood boundaries are available except for the Poudre Park area and the reach downstream from the canyon mouth. Based on field inspections, however, residential areas 15 feet or less above the streambed have been identified on the plates. At Poudre Park, the 100-year flood averages about 15 feet deep; therefore, this depth was used as an approximate standard. Low-level campgrounds and picnic areas have also been identified. Areas of the highway which appear high enough and far enough away from the stream are designated as safe highway areas. Evacuation arrows indicate typical locations where floods may be escaped on foot, although the highways at those locations are not necessarily safe. The hazard evaluation was focused primarily on the main river. There may be hazards from significant side tributaries if intense rain falls on them. Since detailed data are not available, plates 5 through 11 serve primarily to give an indication of the flood hazard.

Table 9 lists the estimated number of buildings in the canyon. Some buildings are probably unaccounted for due to restricted access. There are about 300 residences in the high flood hazard areas which are 15 feet or less above the streambed. A large number of residences at higher levels would be affected indirectly by flooding. About one-half of the residences are occupied year-round; the remainder are vacant during the winter. The U.S. Forest Service estimates that during the height of the tourist season there may be 1,000 to 1,200 overnight campers in the Cache la Poudre River canyon. Some of the areas designated as picnic areas can also facilitate campers. Tourists might camp at locations not designated on any map. It is estimated that 2,000 or more tourists may be in the canyon during daylight hours because of daytime activities such as picnics or fishing.

Table 12
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
1	Barnes Meadow	None	Generally Satisfactory	100	Adequate	Vacation homes, Spencer Heights, Colorado Hwy 14	Redesign spillway so embankment not eroded, strengthen riprap, repair service spillway and outlet as needed, trim trees and brush	Watch embankment erosion, downstream warning
2	Black Hollow	None	Generally Good	20 - 30	Seriously inadequate for high hazard class	Colo. Hwy. 14, Loop Lake, town of Severance	Check undercut of stilling basin, maintain upstream concrete face, emergency plan, monitor seepage, repair gate house	Watch overtopping, spillway, and stilling basin erosion
3	Chambers Lake	Joe Wright Dam (under construction)	Embankment only marginally stable	40	Seriously inadequate	Cabins, shops, camping facilities, Colorado Hwy 14	Maintain water level lower than 45 feet, evaluate stability and seepage, rehabilitate, raise low area in right dike abutment	Watch overtopping, seepage, embankment stability, downstream warning
4	Cobb Lake	Hinkley Lake	Good	100	Adequate	Farms, trailer court, multiunit dwellings u/s of Hwy 14	Add riprap, remove trees, inspect outlet, monitor seepage	Routine observation, downstream warning
5	Comanche	None	Poor	10	Seriously inadequate	Campground, ranch	Enlarge spillway, monitor and evaluate seepage, trim vegetation	Watch overtopping and seepage

Table 11 (Cont'd)
Pertinent Data for Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Inventory No.	Owner	Stream	D.A. (mi^2)	Height (ft.)	Normal Storage (acre-feet)	Storage at Dam Top (acre-feet)	Surcharge[1] Storage (inches)	Spillway Location
29	Water Supply & Storage No. 4	CO 01759	Water Supply & Storage Company	Offstream	0.30	Approx. 30	1,480	2,020	33.75	East abutment
30	Windsor Lake	CO 00853	Windsor Reservoir & Canal Co.	Offstream	5.60	41	17,087	21,100	13.44	Natural ground between main embankment and dike, 1000 ft. right of Outlet
31	Windsor No. 8	CO 00855	Windsor Reservoir & Canal Company	Offstream	1.58	60	9,884	12,391	29.76	None

(1) Available storage between normal storage and top of dam expressed as inches of rainfall uniformly spread over upstream drainage area. Does not include spillway releases.
(2) Not included in recent National Dam Safety Program inspections.
(3) Masonry circular arch embankment
(4) Spillway is notch in masonry embankment
(5) Spillway is "bathtub" inlet and chute
(6) Rock-cut spillway
(7) Rolled earth embankment including low concrete parapet wall along crest of dam
(8) Concrete-lined earth-cut and rock-cut spillway
(9) Concrete spillway

Table 11 (Cont'd)
Pertinent Data for Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Inventory No.	Owner	Stream	D.A. (mi^2)	Height (ft.)	Normal Storage (acre-feet)	Storage at Dam Top (acre-feet)	Surcharge[1] Storage (inches)	Spillway Location
23	Rocky Ridge	CO 02020	Water Supply & Storage Co.	Offstream	1.31	35	3,200	4,650	20.76	Left abutment
24	Seaman[7]	CO 00143	City of Greeley	North Fork Cache la Poudre River	545.00	105	5,000	7,900	0.10	Left of left[8] abutment
25	Terry Lake	CO 00850	Larimer & Weld Reservoir Company	Offstream	4.96	40	9,200	10,700	5.67	Right abutment
26	Timnath Reservoir	CO 00851	Cache la Poudre Reservoir Company	Offstream	20.70	43(S) 20(W)	9,900	16,200	5.70	Left abutment of south dam
27	Warren Lake	CO 00852	Warren Lake Reservoir Co.	Offstream	0.86	23	2,100	2,354	5.54	On embankment[9] near right end
28	Water Supply & Storage No. 3	CO 00154	Water Supply & Storage Company	Offstream	0.51	41	3,350	4,300	34.93	Left abutment

Table 11 (Cont'd)
Pertinent Data for Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Inventory No.	Owner	Stream	D.A. (mi^2)	Height (ft.)	Normal Storage (acre-feet)	Storage at Dam Top (acre-feet)	Surcharge[1] Storage (inches)	Spillway Location
17	North Poudre No. 3	CO 00838	North Poudre Irrig. Co.	Offstream	3.38	36	2,750	3,600	4.71	None
18	North Poudre No. 5	CO 02018	North Poudre Irrig. Co.	Offstream	3.30	37	Approx. 4,500	8,650	23.58	Right abutment
19	North Poudre No. 6	CO 00841	North Poudre Irrig. Co.	Offstream	2.30	39	4,560	11,400	55.76	None
20	North Poudre No. 15	CO 00842	North Poudre Irrig. Co.	Offstream	1.90	50	5,517	7,177	16.38	Right abutment
21	Park Creek	CO 00146	North Poudre Irrig. Co.	Park Creek	5.13	103	7,343	10,460	11.39	In saddle to[6] right of dam
22	Richards	CO 00845	Water Supply & Storage Co.	Offstream	0.40	20	515	950	20.39	None

Table 11 (Cont'd)
Pertinent Data for Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Inventory No.	Owner	Stream	D.A. (mi^2)	Height (ft.)	Normal Storage (acre-feet)	Storage at Dam Top (acre-feet)	Surcharge[1] Storage (inches)	Spillway Location
9	Halligan[3] Reservoir	CO 01169	North Poudre Irrig. Co.	North Fork Cache la Poudre River	399.00	95	6,400	9,312	0.14	Center of dam[4]
10	Indian Creek	CO 00139	North Poudre Irrig. Co.	Offstream	3.35 (16.6 w/Dam B-4)	46	1,906	2,726	4.59 (0.93)	Left abutment
11	Joe Wright	CO 01766	City of Fort Collins	Joe Wright Creek	5.79	140	7,161	9,353	7.10	Left abutment[9]
12	Kern Reservoir	CO 00854	Kern Res. & Ditch Co.	Offstream	4.40	12	1,240	1,870	2.69	None
13	Kluver Reservoir	CO 02036	Water Supply & Storage Co.	Offstream	0.39	25	1,100	1,800	33.66	North abutment
14	Long Draw Reservoir	CO 00140	Water Supply & Storage Co.	la Poudre Pass Creek	8.41	84	10,900	14,200	7.36	Main Embankment[5]
15	Long Pond	CO 01174	Water Supply & Storage Co.	Offstream	1.79	34	Approx. 2,500	4,080	16.55	None
16	North Poudre No. 2	CO 00837	North Poudre Irrig. Co.	Offstream	5.00	27(East) 15(West)	3,360	4,450	4.09	(Two) E&W abutment

Table 11
Pertinent Data for Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Inventory No.	Owner	Stream	D.A. (mi^2)	Height (ft.)	Normal Storage (acre-feet)	Storage at Dam Top (acre-feet)	Surcharge[(1)] Storage (inches)	Spillway Location
1	Barnes Meadow	CO 00123	City of Greeley	Offstream	3.09	51	2,349	3,100	4.56	In embankment at right abutment
2	Black Hollow	CO 01157	Water Supply & Storage Company	Black Hollow Creek	20.80	42	8,058	9,300	1.12	(Two) right & left abutment
3	Chambers Lake	CO 00127	Water Supply & Storage Company	Joe Wright Creek	30.60	58	8,750	11,400	1.63	Left abutment
4	Cobb Lake	CO 00129	Windsor Reservoir & Canal Company	Offstream	2.90	58	22,300	28,200	38.15	Left abutment
5	Comanche	CO 00130	City of Greeley	Big Beaver Creek	11.94	40	2,620	3,240	0.97	Right abutment
6	Douglas Reservoir	CO 01163	Windsor Reservoir & Canal Company	Dry Creek, Poudre Valley Canal	46.40	39	8,300	11,700	1.38	Left abutment
7	Eaton [(2)]									
8	Fossil Creek	CO 01165	North Poudre Irrig. Co.	Fossil Creek	28.26	42	11,100	16,640	3.68	Remote right abutment

was given to items related to embankment stability such as leakage, erosion, seepage, slope instability, undue settlement, displacement, tilting, cracking, deterioration, and improper functioning of drains and relief wells.

Conditions relating to structural adequacy were observed during the dam inspections. These conditions included a spillway discharge positioned so it could erode the embankment, a lack of riprap or vegetation which could promote erosion, an uneven spillway or embankment level which could cause flows to concentrate and rapidly erode, erosion at the outlet works discharge, and excessively steep slopes. Another potential hazard is "piping"; with this condition, water under pressure can find a path through the embankment by way of small openings. These openings can rapidly be enlarged by erosion. The possibility of this condition was indicated by trees on the embankment, which could leave root holes; by rodent holes; or by seepage.

RESULTS OF DAM INSPECTIONS

The results of the dam inspections are summarized in tables 11 and 12. The number preceeding the name of each dam can be used to locate the dams on plate 12.

Elevations in tables 11 and 12 usually refer to a local datum, generally the low point at the upstream side of the dam. In table 11, the inventory number is a designation used in Corps of Engineers and State of Colorado records and should be used if requesting further information about a particular dam. A dam located "offstream" is usually in a normally dry gulch and its water source is a canal or another upstream dam.

The letters "D.A." refer to the drainage area contributing to the dam.

Practically all dams inspected in the Cache la Poudre River basin fall into the high hazard and intermediate or large size category. Therefore, in the inspection results presented in this report, dams with the hydrologic capability to pass 100 percent of the PMF without overtopping are termed "adequate". Alternative floods were passed through the dams, with discharges being various percentages of the PMF discharges. Dams that pass 50 percent of the PMF but less then 100 percent of it are termed "inadequate". Dams that cannot pass 50 percent of the PMF are considered "seriously inadequate".

Although the capacity to pass a PMF is a principal factor, structural deficiencies should be considered. Some of these are identified in the next section, which discusses dam safety inspection procedures.

INSPECTION PROCEDURES

A Phase I Inspection Report has been prepared under the National Dam Safety Program for about 30 dams in the Cache la Poudre River basin. The purpose of the inspection was to make a general assessment of structural integrity and operational adequacy. In order to identify hazardous dams expeditiously, the scope of the Phase I inspection was based on available engineering data, a detailed visual field inspection, and a hydrologic analysis. The inspection determined needs for emergency measures or additional studies.

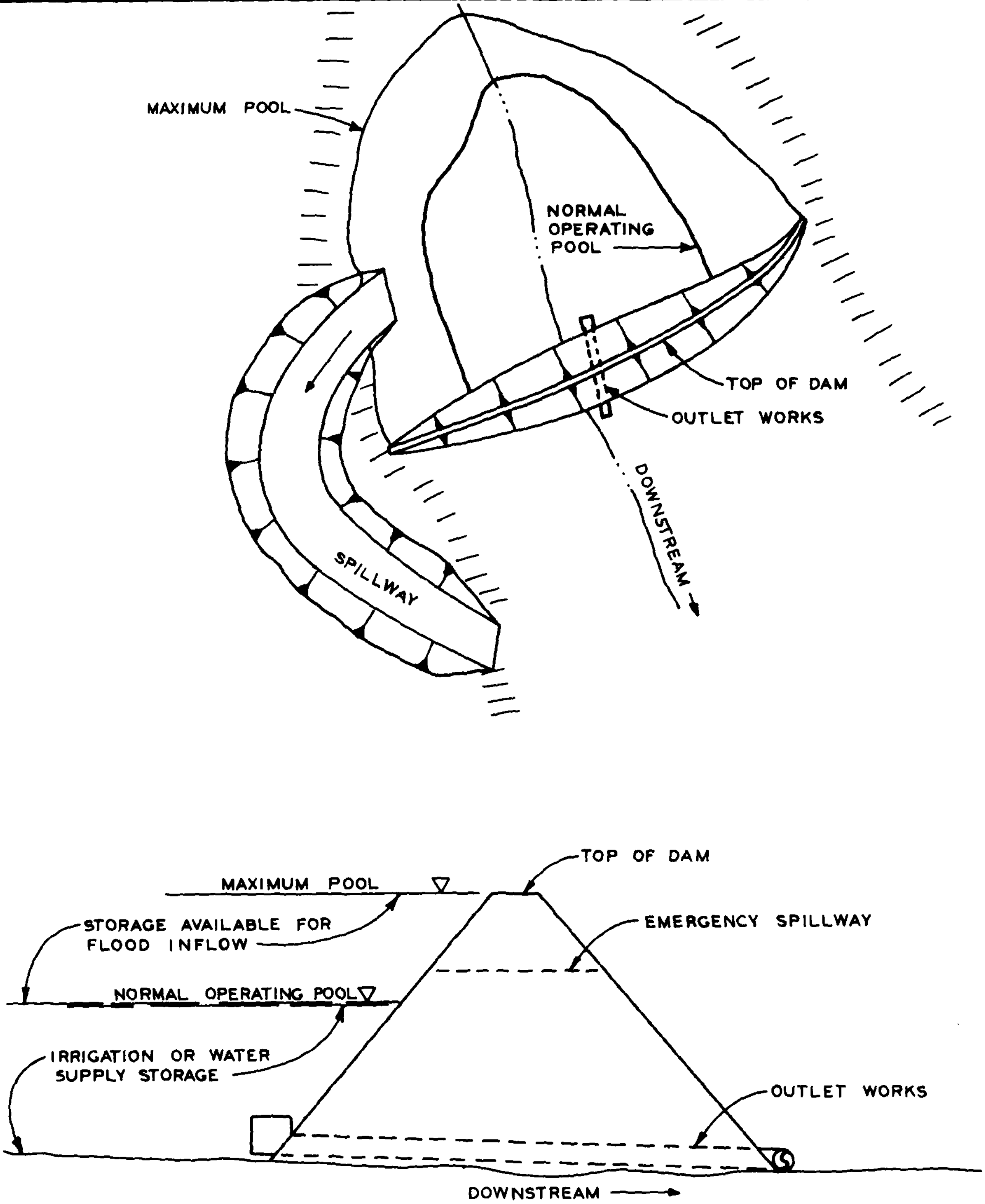
The hydrologic studies were made to determine the capability of handling the PMF. During the field inspection, information on construction, maintenance history, and operating procedures was gathered. A detailed inspection checklist covered each part of the dam, including the crest, upstream slope, downstream slope, abutment contacts, intake structure, outlet works conduit, stilling basin, spillway, gate structures, the reservoir area, and instrumentation. Particular attention

drainage areas. The reservoirs are often connected by canals. The dams typically have a normal operating pool several feet below the embankment top. Irrigation reservoirs maintain this pool during the late spring and early summer. The water level is usually lower during the fall and winter. Some reservoirs may be dry in winter. The normal operating pool is the pool that could be expected during the flood season. The storage available to handle an incoming flood without overtopping, as shown in figure 1, is the volume between the normal pool and the maximum pool or top of the dam.

The outlet works, sometimes called the "service spillway", is usually a concrete conduit with a small intake structure and a gate with its controls located on the top of the dam. It is used to drain the reservoir or release irrigation water. Most of the inspected dams have an emergency spillway; the spillway is usually an earth-cut channel through the natural ground to allow excessive flood inflow to bypass the embankment without overtopping. Some dams, however, were built without spillways.

From the standpoint of dam safety, the hydrologic design of a dam aims at avoiding overtopping. Overtopping is especially dangerous for an earth dam because the downrush of waters over the crest may breach the dam embankment.

The Corps of Engineers designs its dams to safely pass the estimated Probable Maximum Flood that could be generated in the basin upstream from the dam. The Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. This is generally the accepted criterion for major dams throughout the world and is the standard for dam safety where overtopping would pose any threat to human life. The PMF is derived by using probable maximum precipitation information that is generally available from the National Weather Service.



TYPICAL DAM FUNCTION AND OPERATION

Table 10
Hazard Potential Classification of Dams

Category	Loss of Life (Extent of Development)	Economic Loss (Extent of Development)
Low	None expected (No permanent structures for human habitation)	Minimal (Undeveloped to occasional structures or agriculture)
Significant	Few expected (No urban developments and no more than a small number of inhabitable structures)	Appreciable (Notable agriculture, industry, or structures)
High	More than a few expected	Excessive (Extensive community, industry, or agriculture)

It should be noted that the hazard relates to the development downstream that would be damaged if a dam failed for any reason. It does not necessarily reflect the likelihood of failure. That is judged by analysis of the dam's structural condition or its hydrologic capability to store or pass a major flood without failure.

An intermediate size dam has a height greater than or equal to 40 feet, but less than 100 feet, and has a storage capacity greater than or equal to 1,000 acre-feet, but less than 50,000 acre-feet. Dams falling below these limits are classified as small, and those above these limits are termed large. The size classification is determined by the storage or height, whichever gives the larger size category.

Figure 1 illustrates typical dam characteristics. The dams inspected in the study area usually store water for irrigation or municipal supply. Almost all of the dams are constructed of earthfill embankments and are located offstream on minor tributaries or in normally dry gulches. Most dams therefore, have relatively small contributing

dam safety legislation and many have the capability t perform or administer their own dam safety program. Colorado has an approved dam safety program.

Dam failures have occurred in the Cache la Poudre River basin and in nearby areas. Chambers Lake dam located in the mountainous part of the basin, failed in 1891 and in 1907. Heavy rains in June 1949 caused Lord Reservoir on Lost Creek to be overtopped; it caused damage to the town of Roggen about 20 miles southeast of Greeley. Heavy rainfall caused the overtopping and failure of Buckhorn Dam on Buckhorn Creek about 10 p.m. on 3 August 1951; this creek is a tributary of the Big Thompson River and the dam is located about 6 miles west of Loveland. This failure caused severe flooding downstream to the vicinity of Loveland. A relatively short distance to the southeast of the Cache la Poudre River basin, spillage from lower Latham Dam caused flood damage to the community of Kersey on 12 April 1973. The Prospect Valley Dam in southeast Weld County failed on 10 February 1980 several hours after a leak was noted at its southeast end. Officials said the failure was probably caused by animal burrowing.

DEFINITIONS

The hydrologic evaluation of inspected dams was based on hazard potential classification and on size. For purposes of the National Dam Safety Program, these are defined in "Recommended Guidelines for Safety Inspection of Dams" by the Department of the Army, Office of the Chief of Engineers.

The hazard potential classification is related to existing development in flood hazard areas downstream from dams, as defined in table 10.

Dam Safety

BACKGROUND

During the course of the Cache la Poudre River Basin Special Study, local officials expressed a desire for greater dissemination of dam safety information at the local level. Therefore, that information has been included in this report.

In August 1972, inspection of non-Federal dams was authorized by the National Dam Inspection Act (Public Law 92-367). The law authorizes the Secretary of the Army, acting through the Corps of Engineers, to carry out a program to inspect dams generally 25 feet or more in height or impounding more than 50 acre-feet of water. This program is known as the National Dam Safety Program.

In 1977, due to several dam failures, interest in implementing the inspection program increased and Congress appropriated funds to carry out the inspections. On 2 December 1977, the President directed the inspection of about 9,000 non-Federal dams that present a high potential for loss of life and property if they fail. He emphasized that this would not relieve the states or dam owners of their responsibilities for public safety.

Of 4,906 dams inspected through March 1980, 32 percent were found to be unsafe.(10) Inspection of the approximately 9,000 high-priority dams was expected to be completed by September 1981.

In order to assist the states in developing effective dam safety programs, the Federal Government has encouraged states to supervise or cooperate in the program activities. Most states now have effective

Table 9
Estimated Development In
Cache La Poudre River Canyon

Reach	Length Valley Miles	Number of Structures: 0 to 15 feet Above Streambed				Over 15 feet Above Streambed			
		Residential	Non-Residential	Camp-Grounds	Picnic Areas	Residential	Non-Residential	Camp-Grounds	Picnic Areas
Spencer Heights Locality	0.6	32	4	-	-	8	-	-	-
Spencer Heights-Kinikinik	3.4	-	-	-	-	7	-	1	-
Kinikinik Locality	0.8	26	1	-	-	1	-	-	-
Kinikinik-Rustic	8.9	87	5	1	-	44	1	-	2
Rustic Locality	0.4	64	-	-	-	30	2	-	-
Rustic-Poudre Park	21.0	18	3	6	8	16	-	-	-
Poudre Park Locality	0.6	51	-	-	-	16	2	-	-
Poudre Park-Canyon Mouth	9.5	27	-	-	-	20	1	-	-
Total	45.2	305	13	7	8	142	6	1	2

Note: Residential includes permanent homes, tourist cabins, and mobile homes.
Nonresidential includes commercial and public buildings.

Table 12 (Cont'd)
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
6	Douglas Reservoir	Park and No. 15	Reasonably Good	15	Seriously inadequate	Larimer Canal, farms, hwys, residences	Enlarge spillway or divert upstream, monitor seepage, add riprap and seeding	Watch overtopping, seepage
7	Eaton (1)							
8	Fossil Creek	Portner, Benson, Donath, Duck, Nelson, Mud, others	Poor to fair	Approx. 50	Inadequate	Farms, I-25	Raise embankment and perimeter areas, enlarge spillway, replace outlet	Watch overtopping
9	Halligan Reservoir	Eaton, minor dams	Inadequate data, possibly overstressed	Below 50	Seriously inadequate	Sparse rural development, Seaman, residences, Ft. Collins area	Detailed structural and hydrologic study, monitor seepage, flood warning	Watch structural stability, seepage, downstream warning
10	Indian Creek	Dam B-4	Very Good	80	Inadequate	Farmhouses	Minor downstream slope erosion repair, check embankment slippage above outlet, repair erosion near outlet, breach berm downstream of dam	Watch for erosion at outlet, watch for embankment slippag over outlet works
11	Joe Wright	None	Excellent	100	Adequate	Colo. Hwy. 14, campground, Chambers Lake	Monitor seepage, regrade minor cracks	Watch seepage, reservoir slides, snow blocking spillway

Table 12 (Cont'd)
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
12	Kern Reservoir	None	Reasonably Good	20	Seriously inadequate	City of Windsor	Provide emergency spillway, repair riprap, inspect outlet works; remove trees from embankment	Watch overtopping, possibly downstream warning
13	Kluver Reservoir	None	Reasonably Good	100	Adequate	Isolated homes, agricultural area	West (low-level) outlet should be maintained or abandoned. Maintain embankment.	Routine observation
14	Long Draw Reservoir	None	Generally Excellent	100	Adequate	Spencer Heights, camping, day-use areas	Add minor riprap, seeding. monitor slope and seepage	Routine observation, downstream warning
15	Long Pond	Richards Lake	Fair to Good	Approx. 87	Inadequate	School, housing development	Provide spillway, limit pool to 5043.2, study stability of outlet, riprap upstream toe	Watch overtopping, outlet stability, downstream warning
16	North Poudre No. 2	None	Fair	35	Seriously inadequate	Dams Nos. 5 & 6, farms, residences, highways	Revise embankment or enlarge spillway, monitor seepage, add downstream drains and riprap, close old outlet	Watch overtopping, seepage, downstream warning
17	North Poudre No. 3	None	Generally Poor	35	Seriously inadequate	Farms, residences, county roads, Wellington	Construct spillway, seal old outlet, investigate seepage, miscellaneous embankment rehabilitation	Watch overtopping, seepage, downstream warning

Table 12 (Cont'd)
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
18	North Poudre No. 5	North Poudre No. 2	Fair to poor	70 unless No. 2 Fails	Inadequate	North Poudre Reservoir No. 6	Enlarge spillway, repair riprap, monitor seepage and slope stability, inspect outlet	Watc overtopping, seepage, downstream warning
19	North Poudre No. 6	North Poudre No. 2 & No. 5	Fair to poor	100 if pool below 24', unless No. 2 & 5 fail.	Adequate unless upstream dams fail	Farms, residences, highways	Construct spillway, repair outlet, monitor seepage, trim brush, add riprap	Watch upstream dams, overtopping, seepage
20	North Poudre No. 15	None	Fair	100	Adequate	County roads, railroad, Douglas Lake	Level crest, repair slope erosion, add left toe drain, prohibit livestock, monitor ground water and embankment, stability analysis	Watch upstream slope erosion, seepage
21	Park Creek	None	Reasonably Good	100	Adequate	Farmstead, local access roads	Remove access road from spillway, check conduit, investigate water supply line leakage	Routine observation, watch access road
22	Richards	None	Reasonably Good	100	Adequate	Long Pond Reservoir	Remove trees, repair riprap and sloughed area, repair conduit exit, provide spillway, monitor seepage at outlet	Routine observation, watch outlet

Table 12 (Cont'd)
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
23	Rocky Ridge	None	Reasonably Good	100	Adequate	Dixon and Terry Lake Reservoirs	Repair erosion at left exit wall, watch steep embankment slopes, repair riprap, remove trees	Routine observation, watch slope stability
24	Seaman	Eaton & Halligan Reservoirs	Reasonably Good	22	Seriously inadequate	Fort Collins filtration plant, a number of homes nearby	Provide adequate spillway, extend slope protection to parapet wall	Watch overtopping, downstream warning
25	Terry Lake	Rocky Ridge, Dixon, Water Supply No. 3 & No. 4	Reasonably Good	100 if crest 38 feet or above	Adequate	Buildings, trailers, U.S. Hwy 287, Ft. Collins	Raise embankment to design, make uniform spillway section, add riprap, monitor toe drain	Watch overtopping seepage, downstream warning
26	Timnath Reservoir	None	Generally satisfactory	100, 80 if inlet dike raised	Adequate	Farms, agricultural areas, town of Timnath	Widen spillway, raise inlet dike, repair riprap voids, monitor toe drains	Watch overtopping, seepage, downstream warning
27	Warren Lake	None	Excellent	100	Adequate	Golf course, rural residences	Repair crack on crest, raise low spot on dam, extend toe drains, monitor embankment slippage and seepage, remove dead trees	Check embankment, low spot, slippage, and seepage

Table 12 (Cont'd)
Adequacy of Major Dams
Cache La Poudre River Basin

No.	Name of Dam	Upstream Dams	Condition	Flood Passed w/o Overtopping (percent of PMF)	Hydrologic Capability	Development Subject To Hazard	Principal Recommendations	Observations During Excess Rain
28	Water Supply & Storage No. 3	None	Reasonably Good	100	Adequate	Water Supply & Storage Reservoir No. 4, Terry Lake	Survey and clean spillway, repair conduit exit, repair riprap, fill rodent holes	Routine observation, watch outlet
29	Water Supply & Storage No. 4	W.S. & Storage No. 3	Reasonably Good	100	Adequate	Residences, Terry Lake	Check stability of outfall headwall, inspect and improve outlet, remove trees, add riprap	Routine observation, watch outlet
30	Windsor Lake	None	Good	100	Adequate	Thompson Lake, farmhouses, Kern Reservoir, town of Windsor	Remedy seepage by diverting irrigation waste, clean or add toe drains, or add chimney drain and fill, remove grazing, trees, cistern	Watch seepage
31	Windsor No. 8	Reservoir No. 9 & 10, pipe to Annex. No. 8 Reservoir	Generally Good	100	Adequate	Elder Reservoir, farms	Provide service spillway, monitor toe drain seepage, movement markers	Routine observation, watch seepage

(1) Not included in recent National Dam Safety Program inspections.

The normal storage is usually that during the irrigation season. The maximum storage is the storage at the dam top. Additional water may have spilled through the spillway. Surcharge storage is the volume available in the space between the normal storage and the maximum storage. In the table, surcharge storage volume is expressed in inches of runoff from the drainage basin. One inch of runoff from one square mile is 640÷12=53.3 acre-feet.

In table 12, the "condition" column refers to a general assessment of the stability and/or state of maintenance of the dam structures. A dam might be in good physical condition and still be too small to deal with large floods. The specific defects for a particular dam are indicated in the "Principal Recommendations" column. The "Observations During Excess Rain" column suggests where attention should be directed during heavy rains; this is based on the findings of the dam inspections. All dams are of earthfill construction and all spillways are earthcut unless otherwise noted.

Table 12 also provides an indication of the hydrologic capability of the inspected dams. Hydrologic capability, in this context, refers to the ability of a dam to pass large floods without overtopping of the main embankment. A dam that can store and/or pass a probable maximum flood without being overtopped has a hydrologic capability designated as "adequate." To determine the hydrologic capability, other floods are assumed to occur at the dams. Each flood has the same hydrograph (discharge versus time relationship at a given location). However, the discharges are reduced to varying percentages of the PMF discharge. A dam that can pass a flood having a magnitude of 50 percent of the PMF, but less than 100 percent of the PMF is termed "inadequate." Dams that cannot pass a flood having a magnitude of 50 percent of the PMF are termed "seriously inadequate."

In table 12, the "Development Subject to Hazard" column summarizes developments downstream from each dam that might be damaged by failure of the dam. The extent of flooding cannot be determined without a hydrologic dam failure analysis.

As a consequence of the dam inspections, some remedial measures have been initiated. The Colorado State Engineer should be contacted concerning the current status of remedial actions.

Inspection reports are available for 30 dams in the Cache la Poudre River basin; of those inspected four dams were found to have "inadequate" hydrologic capability and nine had "seriously inadequate" hydrologic capability. The dams with less than adequate hydrologic capability are listed in table 13.

Table 13
Hydrologically Inadequate Dams

Number in Table 11 and 12	Name of Dam
2	Black Hollow
3	Chambers Lake
5	Comanche
6	Douglas Reservoir
8	Fossil Creek
9	Halligan Reservoir
10	Indian Creek
12	Kern Reservoir
15	Long Pond
16	North Poudre No. 2
17	North Poudre No. 3
18	North Poudre No. 5
24	Seaman

Flood Warning

In view of the experience of the 1976 Big Thompson Flood, Larimer County officials have expressed a desire for an analysis of flood warning plans. This section discusses flash flood warning against floods originating from the mountainous part of the Cache la Poudre River basin. Flash flood fatalities and damages had a dramatic increase during the 1970's throughout the Nation; this prompted the American Meteorological Society to issue a statement of concern.[15]

STUDY PROCEDURE

An outline of a flash flood warning system, examples of flash flood warning systems, and potential problems and benefits of warning are discussed below. Measures for flash flood detection were investigated during this study. Potential components of flood detection plans were identified, alternative flood detection networks were developed and evaluated, and local interests were advised on the selection of a flash flood detection network.

Experience in flash flood detection is limited; therefore, literature searches and inquiries were made to determine (1) the experience of others, (2) factors related to flood warning, and (3) types, capabilities, and costs of equipment that might be used.

FLOOD PREPAREDNESS

Flood preparedness can be considered a part of overall disaster preparedness. Flood warning is one element of flood preparedness. For a successful flood preparedness plan, however, several other elements are necessary. A valuable guide for flood planning has been developed

by Owen.[30] Flood preparedness is also outlined in a publication by the Hydrologic Engineering Center, Corps of Engineers.[31]

Elements needed for a flood preparedness plan include warning, evacuation and rescue, temporary damage reduction measures, recovery, public information, plan implementation, and plan maintenance. Two reports by the Nashville District, Corps of Engineers [1],[2] are examples of detailed warning dissemination and evacuation plans, including personnel, equipment, and organization required. Flood warning plans have been published for two basins located in the Denver metropolitan area.[6],[34]

FLASH FLOOD WARNING

Flash floods are differentiated from other floods by the short time between the causative event, such as heavy rainfall, and the flood peak. As the available time for preflood action becomes shorter, the importance of warning increases and the importance of damage reduction decreases. If the warning time is very short all efforts should be directed to the safety of endangered persons -- with no time lost for protection of property.

OUTLINE OF FLASH FLOOD WARNING SYSTEM

Forecast. The responsibility for predicting flash floods based on atmospheric conditions has been given to the National Weather Service (NWS). The NWS is also responsible for issuing warnings. The NWS has provided assistance and technical guidance in establishing local flash flood warning systems (FFWS). The NWS is concerned with a large geographical area. Private meteorological consultants can be employed to provide forecasts for specific locations. Forecasting is discussed later as a part of flash flood detection.

Detection. Flash flood detection involves the sensing of physical phenomena such as heavy rainfall or rising streamflow by instruments or by visual observation. These data must then be successfully transmitted to an emergency operations center or other command location where the data can be used in decisionmaking. The conditions under which volunteer observers will be activated should be determined, in the emergency plan along with the means of activation. Automatic detection networks should operate full-time during the flood season. The type of reports and procedures for handling incoming data should also be specified in the emergency plan. Specific alternatives for flash flood detection will be discussed later.

Evaluation. The evaluation of a flash flood threat at the local level is based on interpretation of incoming data from the flash flood detection network or on warnings issued by the NWS. An infrastructure of community arrangements is necessary to effectively use hydrologic information. Incoming data may consist of phone calls with fragmentary information, trained volunteer observers telephoning to report rain or rising streams, or printouts of data from automatic instruments. The decision process may be based on past experience, consultation with the NWS, or graphs or tables provided by the NWS. The most sophisticated evaluation is done with minicomputers preprogrammed with a hydrologic model of the basin. The minicomputer would provide predicted flood discharges based on real-time input of rainfall or streamflow data from automated sensors. The sophistication of the decision process should be commensurate with the quality and speed of incoming data.

Issuance of Warning. The NWS has been charged by law with the responsibility for issuing weather warnings. Warnings should be issued by, or coordinated with, the NWS. The NWS issues warnings when it considers them necessary, regardless of whether warnings by others are issued. The circulation of two or more warnings will create public confusion and may be worse than no warning at all. (Interview with

Mr. Ellis Burton, Denver Weather Service Forecast Office, 20 December 1979).

The publication by the Hydrologic Engineering Center, Corps of Engineers, outlines various factors to consider in the decision to issue a warning, in the dissemination of a warning, and in assessing the response to a warning.

The warning decision process should:

- Be made by responsible official or agency if possible;
- Be made with knowledge of current and projected flood threat;
- Be made considering the decision time which is influenced by the nature of the stream;
- Be made with consideration of the specific location of people and not merely to people in general; and
- Avoid false alarms which reduce credibility of system.

The person who issues the warning has a bearing on its credibility. For mass media warnings, a known local official should be responsible. Local officials, such as policemen or firemen, should issue door to door warnings if possible. Where large masses of people are threatened, the use of businesses, churches, schools, and other social organizations is probably the most effective means of issuing a flood warning.

The time of day or day of week will influence the type of warning given. Typical activities at various times include:

- Weekday: Many people at work, school, at home.
- Night: People at home, asleep.
- Weekend and holidays: People at home, recreation.

The content of the warning is very important in motivating the community. It is also necessary to continuously repeat the warning to

ensure public response. The content of the warning message should include:

- Allowable time for evacuation; minutes, hours, days;
- If known, the relationship of the predicted flood crest to familiar landmarks or recent historic flood events, keeping in mind that the flood might go higher; and
- Specific instructions as to the appropriate course of action, such as where to go and what route to take.

Dissemination. Dissemination of the flash flood warning messages is an important task. A warning must reach the entire community, including handicapped persons and remote areas. Methods of dissemination include:

- Radio: Probably the best mass media system since almost everyone has a transistor or car radio which may be used during power failure.
- Television: May reach a large number of people, but is subject to power failure.
- Sirens: May reach large masses but may be difficult to distinguish between other warnings, such as for tornados.
- Telephone: Can be effective but highly subject to line failure during severe storms.
- Door to Door: Most effective warning system and necessary for many flood conditions to assure that everyone receives notice of the flood threat.
- Public Address System: May be effective in disseminating warnings quickly to groups of people in buildings or in remote areas.

Special radio networks, such as law enforcement radio systems, citizens band, or ham radios, and tone activated radios or paging units, which, while not reaching every individual directly, could aid in the dissemination process.

Response. The benefits of a warning system are ultimately determined by the response of disaster preparedness agencies and the public.

People respond to warnings in different ways, some may react immediately and others may either disbelieve the warning or be reluctant to leave until it is too late for rescue. Factors that motivate people to respond to a flood warning are:

- Time of day or day of week.
- Number of times a warning is received.
- Visual recognition of a flood threat (rainfall, rising streams).
- Reception of a warning from a known public official, such as the mayor, or a policeman, or from a relative or person well known, such as a neighbor, member of a community organization, or a business associate.
- Content of warning
- The time elapsed since a past flood event; if a flood has occurred within the memory of a person, the response is usually more positive.
- Recognition of other people evacuating the area.

Since the dissemination and response to a flash flood warning are relevant to the potential benefits of a warning system, these are discussed later in evaluations of existing systems and case studies of past floods.

EXAMPLES OF FLASH FLOOD WARNING SYSTEMS

To aid in considering the establishment of a flash flood warning system, some examples of existing systems are presented. In addition to the publications previously cited, additional guidance on warning

systems can be found in reports by the Susquehanna River Basin Commission[29],[32] and by Downing.[14]

The Susquehanna River Basin Commission (SRBC) has been active in developing self-help flood warning systems which operate at the sub basin level. As of June 1978, there were 16 such systems in operation and they covered over 5,000 square miles in Pennsylvania. Additional systems are being installed.

A prototype system is currently (October 1981) being installed by the NWS in cooperation with the Appalachian Regional Commission in a 12-county region at the intersection of Kentucky, West Virginia, and Virginia. The system includes cooperative observers, radio rain gages, and automatic sensors. Altogether, there will be some 100 rain gages, 60 stream gages, 12 microprocessors at the county level, and 3 minicomputers at state emergency operation centers. The minicomputers at state level further process data and communicate with the NWS and other emergency organizations. Expansion to an 80-county area is being planned.[8]

The community of Gatlinburg, Tennessee, has a flash flood warning system installed in 1980. The basin upstream from the city is 41.6 square miles and the warning time for floods ranges from about 1/2 hour to 2 hours. High ground in most areas however, is 100 yards or less away. The city, the Tennessee Valley Authority, and the NWS concluded that traditional manual rain gages or upstream warning gages were not adequate. The system consists of five rain gages, two stream gages, and a central station. All gages have self-contained power and communicate by radio, except for a stream gage in the center of the city which reports by telephone. The central station is at the fire department. At this location, there is a minicomputer to utilize incoming data in a software hydrologic model of the basin. The only manual operator input is a flash flood potential index that is

Based on experience in the Big Thompson River flood, comments by Larimer County officials and the NWS, and experience in other floods, telephone communication is considered unreliable. Therefore, all flash flood detection alternatives will be designed using radio communication.

In formulating alternatives, a range of technology was considered -- from completely volunteer to completely automated systems. To explore the effect of fund limitations or phased development, the geographic scale of alternatives was also varied. Regardless of scope, each alternative was designed to provide some protection from both main stem and North Fork floods.

Although the area primarily subject to flash floods is east of the 9,000-foot elevation, local officials are also concerned about dam failure and snowmelt floods. There are several dams upstream from Spencer Heights. Also, a considerable number of residents have moved into the area upstream from Rustic. In order to identify the costs of flash flood warning, the cost of a dam failure flood warning was computed separately.

POTENTIAL COMPONENTS OF ALTERNATIVES

Existing Flash Flood Detection. The NWS has about 35 to 40 volunteer ground observers or "spotters" in Larimer County. Most of these are apparently in the plains region. The NWS spotters report to the Larimer County Sheriff's office who in turn reports to the NWS. As an interim flood warning measure, a local private weather consultant has been retained by Larimer County. The consultant maintains a spotter network of about 80 persons. Each has been furnished with a plastic rain gage. They telephone the consultant if 0.50 inches of rain is received in an hour. The consultant also has a color radar, which displays images from NWS radars at Limon, Colorado and Cheyenne,

The primary areas to be protected are the residences and campgrounds in the Poudre Canyon and the Bellvue, Laporte, and Fort Collins area.

Along the Front Range, the likelihood of heavy rainfall decreases with increasing altitude. The cloudburst zone which is prone to flash flooding is generally considered to lie below elevation 8000 feet m.s.l. The west edge of the heavy rainfall pattern of the 1976 Big Thompson River storm appeared to lie at approximately 9,000 feet m.s.l. Therefore, in designing flash flood detection alternatives, rain and stream gages were placed only in the area east of the 9,000-foot elevation contour. This is approximately the area east of Rustic.

Stream gages should be confined to the main stem in the Poudre Canyon and to the main stem of the North Fork. The Poudre Canyon is the only densely populated flood plain area. The North Fork area is sparsely populated but produces floods that threaten the Fort Collins area. Placing stream gages on tributaries would require an excessive number of gages with little increase in warning time.

The potential size of flood producing storms affects the design of alternatives. The core of the 1976 Big Thompson River storm, taken as the area with 8 inches or more of total rainfall, was an ellipse or oval approximately 5 miles wide and 10 miles long. For other past storms in the region, the core of the highest rainfall areas also resembled ellipses ranging in dimension from about 4 by 8 miles to 10 by 30 miles. To avoid missing the core of rainfall, and thus severely underestimating the storm, rain gages, where used, should be spaced no more than about 5 miles apart, or about one gage for each 25-square mile area. Stream gages, where used, should also be spaced no more than about 5 miles apart. Volunteer gages should meet the requirement of being at or near a residence. Automatic gages were assumed to require the proximity of an access road.

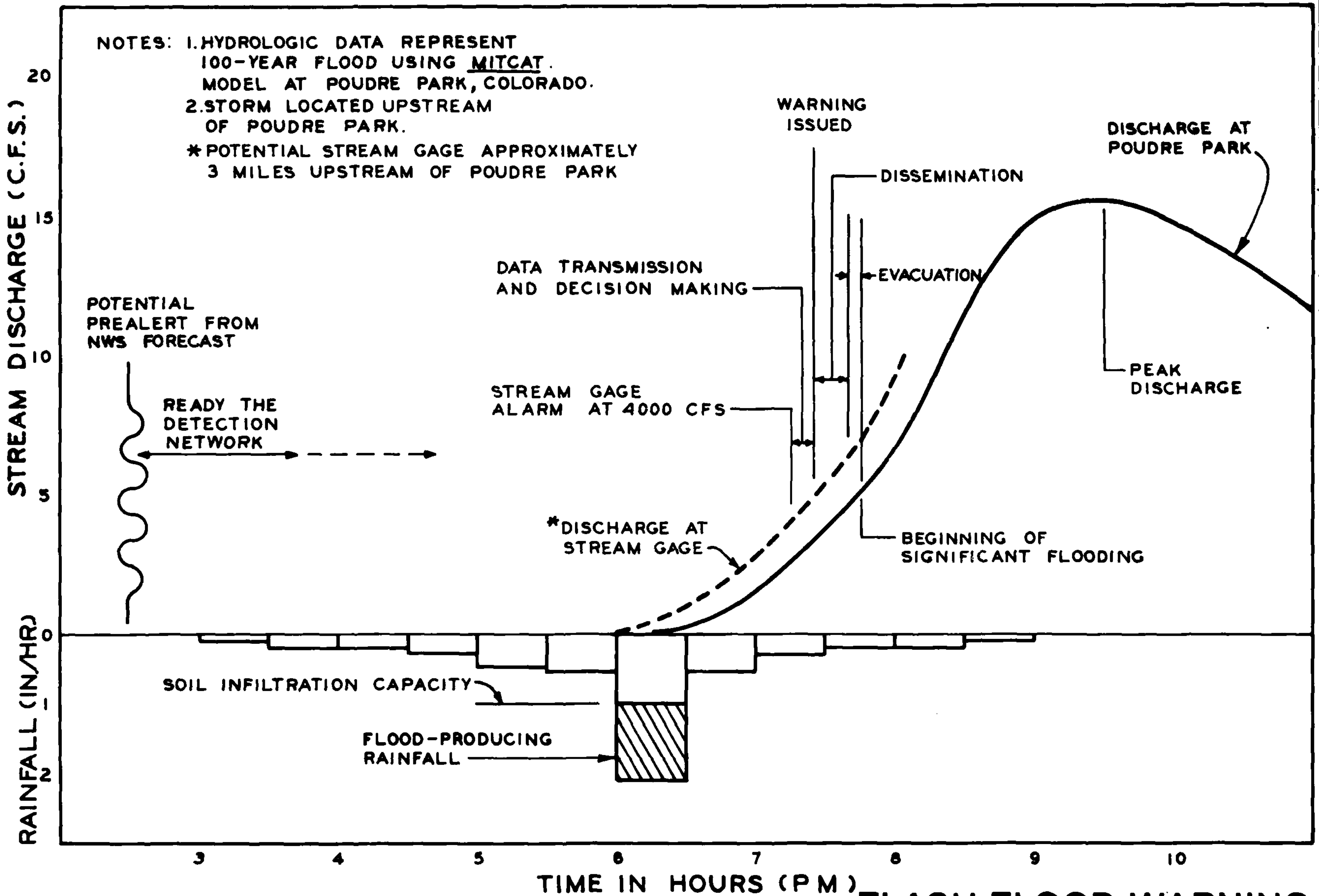
isolated residences, and six major campgrounds. A contact might consist of an emergency radio, telephone, or face-to-face notification. After a contact, the warning should "fan out" through the community or group. This assumes not everyone would be reached by mass media.

In addition to comments made earlier in the case studies, some other observations could be made. The evacuation of the Poudre Canyon would best be done by climbing the sides of the canyon at the nearest available point. The only route through the canyon would probably be cut at several points during a flash flood. Those in the canyon would be isolated until rescued. A few side roads are available, but some of these are located on tributaries which may also flood. Telephones are unreliable. The development in the Poudre Canyon is on a narrow strip along Colorado Highway 14; this might indicate that loudspeakers would be effective in dissemination. To improve response, warnings should be repeated frequently and public education should be part of the flash flood preparedness program.

FLASH FLOOD DETECTION ALTERNATIVES

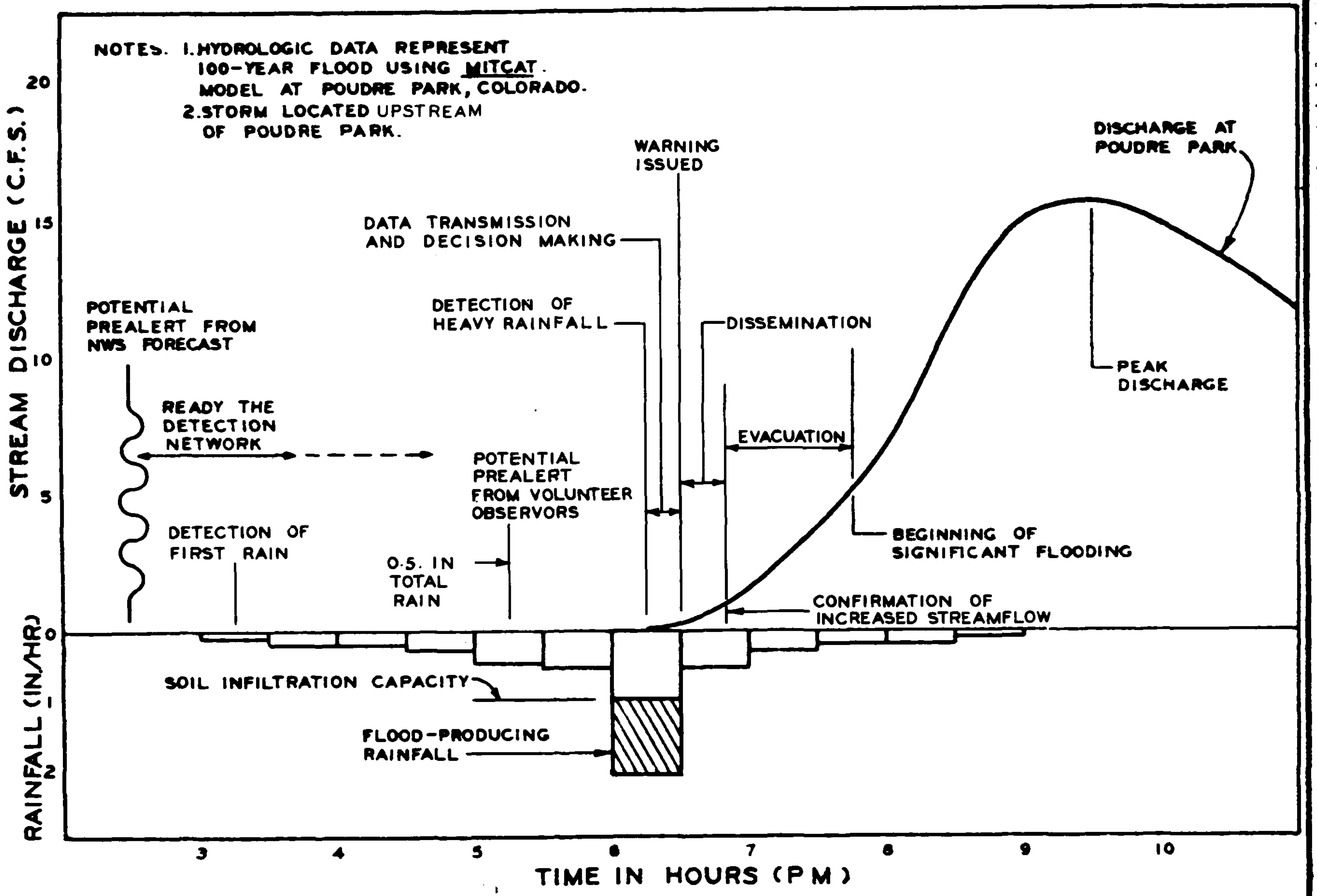
FORMULATION CONSIDERATIONS

The objective of the flash flood detection alternatives developed in this report is to provide as much lead time as possible for decision making, dissemination of warning, and public response, at as low a cost as possible, consistent with performance.



FLASH FLOOD WARNING BY STREAMFLOW SEQUENCE OF EVENTS

VOLUME I FIGURE 3



FLASH FLOOD WARNING BY RAINFALL SEQUENCE OF VENTS

VOLUME I FIGURE 2

Figure 2 illustrates the sequence of events in a flash flood warning at Poudre Park, based on rainfall observations. In most cases, it is expected that there would be a NWS forecast. A prealert could be activated at various points, such as after 0.5 inches of rain had fallen. It is assumed that a measurement of heavy rain for 15 minutes would be required to establish credibility of detection. In figure 2, another 15 minutes were allowed for data transmission, interpretation, and issuance of a warning -- with 20 minutes for dissemination of the warning within Poudre Park. The time available for evacuation is, thus, 55 minutes. This assumes an efficient warning and communication system.

For flash flood warning using an upstream alarm gage set at 4,000 c.f.s., the sequence of events is displayed in figure 3. In this case, warning is more definite, so 10 minutes was allowed for data transmission and decision making and 15 minutes for dissemination within the local community. For a nearby storm, less warning time is available using streamflow rather than rainfall as a warning indicator.

Lives have been saved in floods with only a few minutes warning. However, the evacuation time could be reduced if communications are hampered. Warnings may need to be issued to other areas at the same time. The time of day would affect readiness. The flood shown at 6 p.m., for example, could occur at 3 p.m. or 9 p.m.

The dissemination task is also affected by the distribution of population. The more dispersed the population, the more effort it takes to reach the same number of people. If it is assumed one notification or "contact" is needed for each community, one contact for each group of two or more residences, and one contact for each isolated residence, it would require 24 contacts within the typical available time of about 2 hours to warn those in the reach from Rustic downstream. This reach includes four communities, seven groups, seven

their level. Most people in the flood hazard area were spread out over miles of countryside.

According to a sample survey after the flood, 52 percent received no warning, 35 percent received one warning, and 13 percent received two or more warnings. About 64 percent of those warned were reached by personal acquaintances. Official warnings reached about one-half of those warned, or only one-third of the sampled victims. Some received two types of warnings. Many of those warned by sirens also had confirmation by face-to-face contact. Almost all had less than 2 hours warning, some only a few minutes. One flash flood alarm stream gage signal was ignored as it had a history of technical problems. Only 17 percent of those who received no warning evacuated before the flood. Of those who got one warning, more than one-third evacuated before the flood. About half of those who received two warnings evacuated before the flood. This survey recommended that the following items be included in a warning system:

- a strong local role in the NWS warning system;
- reliable water level alarms;
- spotters with radios;
- warning notification plans;
- loudspeakers rather than sirens;
- repeated warnings rather than a single warning; and
- 24 hour radio broadcast in emergency.

DISSEMINATION AND RESPONSE

The preceding case studies indicate some of the difficulties in warning dissemination and response and some suggestions for improvement.

In the Cache la Poudre River Canyon, warning time is short, and the population is scattered along a long narrow valley bottom.

received no warning -- the rising streams or the rainfall was the only warning. Of those receiving warning, 60 percent were contacted by law enforcement officials -- the remainder by friends or strangers. Warnings were by telephone or face-to-face contact. Of the sample warned, 61 percent received one warning, 38 percent received two or more warnings, and 88 percent attempted to confirm the first warning. Those who climbed the canyon sides had the best chance to survive. Many who tried to drive out were drowned. It is noted that only 26 percent of the received messages specifically said to go to higher ground. Most messages indicated generally to "get out". Some of the recommendations in this study were:

- Install signs indicating the canyon sides should be climbed in case of a flood;
- Provide prior public education to facilitate public action;
- Include campground operators in planning so law enforcement officers could concentrate on other areas;
- Seal off canyon entrances to outside traffic during the emergency; and
- Repeat warnings to get the message across.

A sample survey was made by Tamminga(33) after the Texas Hill Country flood of August 1978. This flood left behind 25 dead, scores injured and millions of dollars in damages. In three counties, nearly 400 homes were destroyed. This was an early morning flood with some communities hit between 4 a.m. and 7 a.m. on 2 August 1978. There had been very heavy rain on the day before; there was a NWS watch the previous afternoon and a warning at 7 p.m. More rain occurred during the night. Local preparedness officials, after being alerted by other agencies and citizens, tried to reach the public by sirens or telephone. Roads, telephones, electricity, and even the police radio were out. The local radio station was off the air at those hours. Residents did not feel sufficiently threatened as past floods had not reached

damage. Studies of the benefits of flood warning in the Susquehanna River[11] and Connecticut River [12] basins indicated that reducible damages constituted about one-third of residential damages. With more than 24 hours of warning, all removable items could be taken out. Partial damage reduction would occur with 6 to 12 hours warning.

From the foregoing, it appears that in the mountain areas, saving of life alone should be considered as a benefit. In the Fort Collins area, it is possible that some property damage might be avoided as a result of a flash flood warning. Aside from flash flood detection, dissemination and public response must be successful in order to achieve the benefits of warning. Some postflood case studies are summarized in the following paragraphs.

CASE STUDIES

Berling[5] commented on the Bureau of Reclamation experience during the 1976 Big Thompson Flood. The lack of historic flood experience made it difficult to believe that a major flood was occurring, but the disaster also indicated the ability of people to rise to the occasion. A command post, manager, continuous team leadership, and careful allocation of key personnel proved effective. Severe lightning knocked out hardwired information systems in the Estes Park area. Berling recommended radio transmitted data. He also stated that in vehicles, AM radios and an alternate transmitting system, such as citizen band, are desirable in case telephones are out of service. A better interface with county and state officials was recommended.

A study by Mileti[27] indicated that during the 1972 Rapid City, South Dakota, flood, only 20 percent of the sampled population acted on receipt of the first warning message.

A study of public warning and response in the Big Thomspon River flood was made by Gruntfest[17]. Of a survey sample, 60 percent

Table 14
Estimated Canyon Population(1)

	Reach	In Established Communities	In Groups of Two or More Dwellings	In Isolated Dwellings	Total
1	Spencer Heights Locality	96	0	0	96
2	Spencer Heights - Kinikinik	0	0	0	0
3	Kinikinik Locality	78	0	0	78
4	Kinikinik-Rustic	21	231	9	261
5	Rustic Locality	192	0	0	192
6	Rustic - Poudre Park	48	0	6	54
7	Poudre Park Locality	153	0	0	153
8	Poudre Park - Canyon Mouth	0	66	15	81
	Total	588	297	30	915

(1) Permanent homes, tourist cabins, or mobile homes 15 feet or less above Cache la Poudre River streambed. Assumed three persons per dwelling unit. Buildings counted by field reconnaissance.

In the table, established communities are those locations designated by a name on U.S. Geological Survey 7 1/2 minute quadrangle maps. These include Spencer Heights, Trading Post, Sportsman Lodge, Kinikinik, Arrowhead Lodge, Glen Echo, Rustic, Indian Meadows, Mishawaka, and Poudre Park. Plates 5 through 11 show the distribution of development in the Poudre canyon.

In addition to local residents, there may be 1,000 to 1,200 persons camping overnight in the Poudre Canyon during the tourist season. Most of the major campgrounds are between Rustic and Poudre Park. The camping season is essentially from Memorial Day to Labor Day. About half the local residents move out during the winter season.

The benefits of flood warning include a reduction in property damage as well as saving human life. According to publications by the Hydrologic Engineering Center, Corps of Engineers, less than 6 hours of available warning time allows only a minimum reduction in property

- Redundant data collection is needed in case one system is out.
- With increasing automated equipment, there has been decreasing interest by remaining volunteer observers.
- Nighttime readings were difficult at staff gages.

PROBLEM AREA

The problem area for flash flooding is defined not only by the extent of flooding but also by the timing of runoff. In the available literature, flash floods have been defined as those having lead times ranging from a few hours to 12 hours. Plate 3 indicates runoff time for mountain floods in the Cache la Poudre River basin. It appears that flash flood warning would be of value for the mountain area and for the plains reach of the Cache la Poudre River as far downstream as the city of Fort Collins.

POTENTIAL PLAN ACCOMPLISHMENTS

POTENTIAL BENEFITS

No economic benefit analysis of a flash flood warning system was conducted. To assess the worth of a system, a qualitative assessment of accomplishments was made.

A flash flood warning should contribute to savings of life within the problem area. The need for this is particularly great along the main stem of the Cache la Poudre River in the mountains downstream from Spencer Heights. This area is hereinafter referred to as the Poudre Canyon or the main stem. The estimated permanent or semipermanent population that would be benefitted by a flash flood warning in the Poudre Canyon is indicated in table 14.

current spotters are members of the Boulder County Fire Department, who watch for forest fires in the mountainous area west of Boulder. It is expected that the spotter network will be more effective as part of an existing organization than it would be as a single-purpose organization. (Telephone conversation with Mr. Don Fraser, Boulder County Communications Department, 11 December 1979 and Mr. Mike Serlet, Public Works Department, 15 September 1981).

Most of the warning systems described in the preceding pages are newly installed. The warning systems in the Susquehanna River basin, however, have been in existence for some time and an evaluation was performed by an Inter-Agency Task Force to determine their effectiveness.(16) Some of the findings are summarized below.

- Observer reports take longer to transmit than automated reports.
- Backup staff gages should be installed at all automated gage stations for public reference.
- Telephone failure is the most serious deficiency of the forecast system.
- New methods of communication are becoming more cost effective.
- Satellite transmission was subject to interruption by high wind at the ground station.
- Satellite or combined radar and satellite imagery is still being developed.
- Remote computer facilities were not always available due to shutdown.
- The most effective flash flood warning system is that operated at the local level.
- Counties should handle flash flood warnings when there is less than 12 hours of lead time.

unable to do because of an insufficient staff. The cooperative NWS-private consultant arrangement has worked well in the Denver region.[13], [20]

As a part of the general Denver flash flood warning system, a basin flood warning system was developed for the Boulder Creek basin, northwest of Denver. The basin is somewhat similar to the upper Cache la Poudre River basin. On the basis of providing longer lead time, reliability, and credibility, a combination of automatic and manual rain gages and automatic and manual stream gages was recommended. A network of 6 radio rain gages, 3 radio stream gages, 60 volunteer rain gages, 4 volunteer stream gages, and 13 radios for volunteers was estimated to cost $160,000 with an annual maintenance cost of $14,000 at 1977 price levels.[24]

The Boulder flash flood warning system was installed in 1979, except for the automatic stream gages which were installed in 1980. The current system has eight automatic rain gages and three automatic stream gages, in addition to volunteer components.

In the Boulder area, prediction of the flash flood hazard is presently based on a table of stream depths and what these mean at downstream points. Curves or tables supplied by the NWS do not adequately define the relationship between rainfall and runoff. The NWS data is used to selectively activate the volunteer network, based on rainfall. Studies are underway to relate basin runoff to rainfall. When this has been determined, it is expected that a minicomputer, which has been installed, will be able to produce real-time hydrographs. A data receiver, printer, and electronic map display incoming data. The minicomputer can also record and display incoming data. With new software, it will be able to analyze the data as well. For redundancy, flood warning facilities are located both at the Boulder County Public Works Department and at the Sheriff's office. The

supplied by the NWS each day. An audiovisual alarm will be activated when the hydrologic model predicts certain stream discharge conditions. The contract cost of the system is about $290,000. The community is in a popular resort area. Visitors are transient, so periodic testing of the system is limited to local officials and business establishments.(23)

A general flash flood warning system has been established for the Denver metropolitan area by the Urban Drainage and Flood Control District (UDFCD), a six-county regional agency. Since 1976 the UDFCD has been active in the area of flash flood warning. The general flash flood warning system involves improved radar capability for the region and the employment of a private meteorologic service to assist the NWS. Within the general warning region, individual basin warning plans are being formulated. It is noted that in order to receive financial assistance from the UDFCD, local interests must agree to maintain the warning system, regulate flood plains, and have a complete warning plan.

To improve radar capability, the UDFCD purchased color radar receivers for the NWS and the private meterological service; they now have immediate access to weather radar images from the nearest NWS weather radars at Limon, Colorado, and Cheyenne, Wyoming. Previously, the Denver NWS office received only inferior quality facsimile images from Limon and no images from Cheyenne. The private meteorological service can issue internal alerts when it determines they are needed. Internal alerts notify officials and are not transmitted to the general public. The private service and the NWS jointly prepare flash flood potential forecasts. The NWS issues the public warnings. The private service relays these warnings in standard format to one location in each county; interpretive guidance on the NWS message is also provided. From the county level, the messages "fan out" to each town. The private service handles a lot of local communication that the NWS is

Wyoming. NWS warnings are called to the consultant, who, in turn, furnishes spotter reports.

Rainfall reports were fragmentary or nonexistent because of telephone failures during the 1976 Big Thompson River flood. In the sparsely populated mountains, if the distance between spotters is more than about 5 miles, the major part of a Big Thompson River type storm may not be reported.

Experience with the NWS spotter network indicates regular telephone contact is necessary to keep the system active and this is not always possible. (Interview with Mr. Larry Tunnel, Denver Weather Service Forecast Office, 20 December 1979). The spotter networks have proved useful in the more densely populated plains area around the city of Fort Collins.[19] In the Boulder area, the number of interested spotters declined in the last few years to about one-third of the original number (with the exception of the Boulder County Fire Department).

The NWS forecasting system is another measure for flash flood detection. At the National Meteorological Center in Maryland, weather is analyzed on a synoptic scale (large scale) basis and rain forecasts are issued to River Forecast Centers (RFC's) and weather service forecast offices (WSFO's) across the country. The RFC's prepare stage forecasts primarily for major rivers with lead times of 12 hours or more. The RFC can provide flash flood guidance for use by the WSFO based on basin configuration and antecedent rainfall. However, the local WSFO is responsible for issuing flash flood watches and warnings.[28] For the Cache la Poudre River basin, the RFC is at Kansas City, Missouri. The WSFO is at Denver.

In addition to spotter networks and forecasts, the NWS might aid in flash flood detection by providing flash flood alarm stream gages, simplified forecasting charts for local use, and assistance in

developing self-contained local warning systems. The extent of these programs is limited by available resources. In the Cache la Poudre River basin, a NWS forecasting table has been developed for Rustic, for internal use by the Denver WSFO. The table relates a range of generalized rainfall distributions on the basin upstream from Rustic to resulting streamflow at Rustic. To help calibrate the tables, the Kansas City RFC issues, twice weekly, a notice of the rainfall needed over a period of 3 hours or so to produce bankfull stages in various Front Range canyon areas. This is known as a Headwater Guidance Advisory.

Records are published for stream gages on the main stem at the canyon mouth and on the South Fork near its mouth. The stream gage at the canyon mouth is read by the State of Colorado. It is also read by the NWS by satellite. Altogether the National Weather Service owns and operates five 8-inch rain gauges, two automated rain gauges and one automated stream gauge on the Cache la Poudre River in Larimer County. Data from the automated gauges are available at Denver approximately every 2 hours and data from the 8-inch rain gauges is available upon request. This data is shared with Larimer County's private weather consultant. Costs of flash flood detection alternatives were computed without assuming the use of existing gages.

Satellites. Techniques for estimating convective or thunderstorm rainfall using satellites have been developed in recent years. One widely used technique uses infrared and visible images of cloud patterns from a geosynchronous (stationary) satellite. Two satellites operated by NOAA are referred to as GOES, (Geostationary Operational Environmental Satellite). Resolution is the capability of distinguishing closely adjacent objects. In photography, it relates to the fineness of detail visible. Resolution of GOES satellites facilities is 1 kilometer (0.6 mile) at visible wave lengths and 8 kilometers (5.0 miles) in infrared. Half-hourly pictures show the growth of cold temperature cloud tops and rainfall is related to this updraft. The rainfall

estimate is increased by observation of certain cloud features -- such as overshooting tops, merging, or stationary storms. Good results have been indicated in some tests, but the method has not been perfected for certain storm types. The National Environmental Satellite Service in Camp Springs, Maryland, makes satellite rainfall estimates on request from WSFO's. There is normally a time delay of 1 1/2 hours or more from the request time to the time users receive data.[9] Satellite images are useful when a storm first starts, but as clouds spread, it becomes difficult to pick out the core of a storm to locate heavy rainfall. (Telephone conversation with Mr. Morry Pauzz, Denver Weather Service Forecast Office, 7 November 1979).

Another use of satellites is to monitor rain or stream gages which have telemetry equipment. The NWS has a limited number of such Automated Hydrological Observing Station (AHOS) sites in Colorado. Most of these report on a 6-hour time schedule.

The U.S. Geological Survey has awarded a contract to test the feasibility of satellite monitoring of hydraulic data. Stream gages are to be queried every 15 minutes with an additional 15 minutes to provide data to the user. About 75 sites will be selected in seven states. No sites are located in the Cache la Poudre River basin. This program began in August 1980.

Radar. NWS weather radars are located at Limon and Cheyenne. A color radar receiver is owned by the local weather consultant retained by Larimer County. The effective range of radar for making reliable estimates of rainfall is about 70 miles. The Cache la Poudre River basin is farther than desirable from the Limon radar but is well situated for the Cheyenne radar. The Limon radar is a WSR-57 network radar and is monitored 24 hours a day. The Cheyenne radar is a WSR-74C local warning radar and is activated whenever precipitation is

occurring or is forecast within the range of the Cheyenne radar, or at the request of the Denver WSFO. The Cheyenne radar should detect most storm conditions. (Interview with Mr. Ellis Burton, Denver Weather Service Forecast Office, 20 December 1979).

Rainfall rates are theoretically related to the intensity of the radar echo or reflectivity from the rain-producing cloud. In this region, however, low-level dry air may cause precipitation to evaporate on the way to the ground. Other factors such as hail may distort the expected relationship between rainfall and radar reflectivity. Ground observation or "ground truth" is needed to verify rainfall intensity levels shown on the radar screen.

In 1979, the Denver metropolitan area flash flood situation was monitored by the NWS and a private meteorological consultant, both using color radar images from Limon and Cheyenne. The probability of detection of flash flood potential days, that is, days in which large thunderstorms produced 1/2 inch or more of rain, was 94 percent, with a 6 percent false alarm rate. Actual flooding was predicted in five of seven events, for a 71 percent probability of detection, and there was a 38 percent false alarm rate. The radar receivers were available for only half of the flood season and only on a dial-up delayed basis. With dedicated phone data lines to the radar receivers ani more experience, the prediction rate is expected to improve.[21]

One possible alternative for flash flood detection would be for local interests to purchase their own weather radar. A NWS-type radar would cost from $125,000 to $250,000; maintenance would cost several thousand dollars a year and a qualified operator would be required. This radar would have to be located away from the mountains so the beam could clear the foothills and sweep over the mountain area. This would be essentially a duplication of the Cheyenne radar.

NWS Forecasting. From the preceding information, it appears that NWS predictions or detection of rainfall would be possible for most storms. The Cheyenne radar (which was installed after the 1976 Big Thompson River flood) is particularly useful in showing rainfall in the mountain portion of the Cache la Poudre River basin. In the event of it being turned off, a scarcity of ground observors, or unusual weather, however, a backup flash flood detection system is desirable. The private weather consultant may increase chances of a successful forecast, with analysis concentrating on a smaller area.

A flash flood warning system dependent on only one device is questionable and redundancy should be incorporated into the system. (Interview with Mr. Ellis Burton, Denver Weather Service Forecast Office, 20 December 1979).

Volunteer Rain Gages. Volunteers for the NWS, private consultants, and the Boulder flood warning system use simple plastic rain gages. During cloudbursts, observers may be reluctant to venture out. Also, observers may report accumulated rainfall but may not know when the rain started. Thus, the intensity of rain may not be well defined. To improve reliability, an outdoor tipping bucket gage would be used. A paper tape recorder could be located indoors and connected by wire to the rain gage. Thus, the observer could be indoors and the time distribution of rain could be seen on the tape.

Volunteer Staff Gages. Volunteer staff gages could be poles of wood, steel, or fiberglass with elevations boldly marked on them. These should be located in the stream near the residence of an observer. Binoculars and a spotlight would be furnished for night observation. Staff gages would be mostly freestanding, although they could be mounted on a bridge if one is suitably located. A depth-discharge relationship would need to be developed for each site.

Volunteer Radios. Volunteers should be equipped with voice radios similar to those used by the Boulder volunteers for proper communication with a base station. These are mobile or portable VHF high-band FM radios. Observers can then be alerted by the base station with FM paging devices. This would increase the reliability of the observation network. A radio for voice communication should be located at the base station.

Automatic Rain Gages. Automatic rain gages of the type described by Burnash and Twedt[7] and in use by the California-Nevada RFC at Sacramento, California, and at Boulder would be used. These are self-contained, event-reporting, tipping-bucket gages which report increments of rainfall by radio to a base station. Station health or functionability is indicated by periodic signals. These gages include a metal cylinder housing about 10 feet high and 1 foot in diameter, a concrete post-hole type foundation, a battery, a tipping bucket gage, an electronics package, a radio transmitter, and an antenna. The battery and some other parts could be removed during the winter or the device could be left out all year.

Automatic Stream Gages. The steam gages would be the same type used at Boulder. These consist of electronic switches, mounted so as to be set off in sequence as the water rises to touch each switch. A depth-discharge rating curve would need to be developed for each gage site. The gages have a transmitter and directional antenna. The operation is entirely electronic and avoids problems associated with mechanical gages.

Repeater Stations. In order to transmit from observers or gages in the mountains to a base station at Fort Collins, repeater stations (relay transmitters on towers) would be needed at high intermediate points in line with both field and base stations. One repeater station would be located in the vicinity of White Pine Mountain in the

southcentral part of the basin to serve the automatic networks. Two repeater stations would be used in the case of voice radio networks; one should be at a high point in the middle reach of the Poudre Canyon. The automatic station transmitters can be more easily located on favorable hills, whil voice radios may need to be located at observer's homes in the can 'on bottoms. Experience with the Boulder flood warning system indicates that line-of-sight transmission is not necessary. For the eleven automatic gages in the Boulder Creek basin, only one repeater in the mountains is used to relay to Boulder. The gages have directional antennas.

Data Receiver, Printer and Display. For automatic rain or stream gage networks, data displays would be used at the base station. One system that is available would require a weather data receiver, weather data terminal, printer, and a basin display board with a lighted number data display for each gage location. The printer and board would show accumulated rainfall for various time periods at each gage or indicate stream levels. Predetermined alarms may be set. Experience at Boulder indicates a display board is not necessary. For information purposes, this item is presented in the cost summary in table 15.

Radar Receiver. Local interests could obtain a color radar receiver such as Boulder County has acquired. It consists essentially of a 19 inch television set with accessory controls. Images from the Cheyenne NWS radar could be viewed directly by officials in Fort Collins. Variations in rainfall intensities over the Cache la Poudre River basin would be displayed by a range of colors. An interface device would need to be attached to the Cheyenne radar and a dedicated phone line from the Cheyenne radar to Fort Collins would be required. The receiver would not control the Cheyenne radar picture and would not receive if the Cheyenne radar were turned off. A color radar receiver is already in use by Larimer County's weather consultant.

Minicomputer and Software. A minicomputer of sufficient capacity could be fed with incoming data from the automatic rain or rain and stream gage networks. A software model of the basin contained in the minicomputer could generate continually self-adjusting predictions of streamflow at various points in the basin. Such a model would probably be justified only for a basin with a complete automatic rain gage network. In addition to a sufficient number of gages, a fairly well defined relationship of basin rainfall to runoff is needed for the model to make meaningful predictions of discharge. At Boulder, a data receiver accepts signals from the repeater in the mountains. A minicomputer connected to the data receiver, displays the data. The minicomputer activates a printer. Analysis of data is done directly from the minicomputer screen or the printer. New software available from the NWS Sacramento RFC will analyze the data and make predictions of runoff. The software is available without charge to governmental bodies. This equipment was assumed to be used in the base station at Fort Collins. The minicomputer can accommodate changes in the data network and could be used for other purposes during the non-flood season.

Weather consultant. Larimer County has employed a weather consultant. A consultant can provide improved liaison between the NWS and local interests, coordinate and receive data from spotter networks, monitor a radar receiver with qualified personnel, provide forecasts tailored to Larimer County's needs, and provide interpretation and guidance on flash flood warning. To avoid conflict, the NWS and private consultants should have an arrangement similar to that established at Denver. For puposes of information, this alternative is included in formulation. Costs for this alternative were obtained from another consultant and may vary.

Coordinator. A flood warning coordinator should be located at the base station. Based on experience at Boulder, this function would require a minimum of one person full-time during the flash flood season,

the 6-month period from about April to September. The coordinator would be alert to general weather conditions, set off pagers to warn volunteer observors, receive data from volunteers or telemetry from automatic instruments, confer with the NWS, monitor the radar receiver (if any), recommend flood warnings to responsible officials, and supervise maintenance of field and office equipment. The coordinator would also keep observor networks active by periodic contact with volunteers, providing public education about flood hazards, and the occasional training of observers.

New Technology. The possibility of cost or technology breakthroughs cannot be discounted. On the other hand, they cannot be guaranteed. Improved methods of estimating rainfall by satellite or radar, increased satellite-monitored sensor networks, or introduction of less expensive sensors are possibilities.

In October 1979, NOAA initiated a 4-year research program entitled Prototype Regional Observing and Forecasting Service (PROFS) at its Environmental Research Laboratory (ERL) at Boulder. The goal is to greatly improve local scale weather services. Forecasts from 12 to 24 hours would be based on continental scale intelligance. Numerical models or minicomputers and near real-time data would be used for forecast periods of less than 12 hours. An operational program may be established at Denver at the end of the PROFS program. A microwave radar is being developed at ERL. This radar will be able to accurately show the rate of rainfall and the total rainfall over a wide area by using a ring of reflectors which returns signals to a small, centrally located radar dome.

New radar techniques and flood warning systems are discussed in a recent report by the Environmental Protection Agency.(26) Application of new technology would be governed by available funding.

COSTS OF COMPONENTS

Table 15 lists the costs used in this report for components of the flash flood detection alternatives. All volunteer and automatic equipment is assumed to be provided by Larimer County and is a cost to the county. For estimating flash floods from rainfall or streamflow data, it was assumed charts or tables developed by the NWS or private consultants would be used. A software model could be developed if sufficient data is available.

Table 15
Cost Components
For Flash Flood Detection

Component	Estimated Purchase and Installation Cost (Without Contingencies)	Estimated Annual Operation and Maintenance
Volunteer rain gage	$ 1,200	$ 70
Volunteer staff gage	1,400	100
Volunteer radio and pager	1,250	40
Automatic rain gage	3,500	200
Automatic stream gage	5,000	400
Repeater station	7,000	200
Base station		
Voice radio	3,000	100
Data receiver	3,000	100
Data receiver, printer, and display	9,500-15,500 (1)	300
Color radar receiver	30,000	200
Dedicated phone line (for radar)	-	600
Minicomputer, printer and software	9,000	300
Weather consultant	-	1,800
Coordinator (2)	-	12,000

Notes:

(1) Varies according to number of field sensing devices.

(2) Based on one person fulltime during 6-month flash flood season.

ALTERNATIVES

A range of flash flood detection alternatives was formulated. These alternatives can be implemented by local interests using the latest known commercial equipment. In all plans, an emergency operations center was assumed to be located in Fort Collins, where resources would be available for 24 hour monitoring if necessary.

The alternatives are classified by their geographic coverage -- minimum, intermediate, or basinwide. The alternatives were also classified according to their method of field observation, i.e., volunteer, mixed automatic and volunteer, or all automatic.

Minimum-Scale Alternatives. Minimum-scale alternative networks are considered to be the smallest size that would provide a significant degree of flood detection. They could be implemented as interim alternatives in the case of phased development. The minimum-scale alternatives use a few stream gages on the main stem and/or North Fork and a minimal rain gage network on the main stem basin. The upper portion of the North Fork basin contributes runoff considerably more slowly than the main stem, is sparsely populated, and covers a large area. Therefore, rain gages and stream gages were placed only in the main stem basin and in that portion of the North Fork downstream from Halligan Reservoir.

Intermediate-Scale Alternatives. Intermediate-scale alternatives were developed of a size between that of the minimum-scale alternatives and that of alternatives treating the entire basin. They appear to be adequate in scope to meet the flash flood detection needs of the study area, as far as is practical. The intermediate-scale alternatives include more rain gages and/or stream gages than the minimum-scale alternatives. For reasons outlined previously, no detection devices would be placed in the upper North Fork watershed.

Basin-Scale Alternatives. Basin-scale alternatives were designed to determine the costs required to provide flash flood detection over the entire mountain area of the basin. Rain gages would be used over the basin between the 9000-foot elevation and the canyon mouth. Additional reaches of the main stem and North Fork would be covered by stream gages. Two alternatives did not involve field detection devices, although by their nature they would cover the entire basin. One of these would be the use of a color radar receiver at Fort Collins which would show the basin as seen by the NWS Cheyenne radar. The other involves the employment of a private meteorological consultant for the Larimer County area.

Description of Alternatives. A summary description of each of the alternatives is presented in the following paragraphs. Alternatives 4, 5A, 5C, 5D, 5E, and 6 are shown on plates 13 through 18.

The minimum-scale alternatives include:

- Volunteer rain and stream gage observers in main stem basin and on North Fork (Alternative 1).

- Mixed network, with volunteer rain and stream gage observers on the main stem supplemented by automatic rain and stream gages in remote areas (Alternative 2).

- Automatic radio-reporting rain gages in main stem basin and stream gages on North Fork (Alternative 3).

The intermediate-scale alternatives include:

- Volunteer rain and stream gage observers in main stem watershed and on North Fork (Alternative 4).

- Mixed network, with volunteer rain and stream gage observers along the main stem supplemented by automatic rain and stream gages in remote areas (Alternative 5A).

- Mixed network, with volunteer stream gage observers along the main stem and North Fork supplemented by automatic rain gages over the main stem basin (Alternative 5B).

- Mixed network, with volunteer rain gage observers over the main stem watershed supplemented by automatic stream gages on the main stem and North Fork (Alternative 5C).

- Mixed network, with volunteer stream gage observers on the main stem and North Fork supplemented by automatic stream gages. No rain gages (Alternative 5D).

- Mixed network, with volunteer stream gage observers on the main stem and North Fork supplemented by automatic rain gages on the main stem basin and automatic stream gages on the North Fork (Alternative 5E).

- Automatic radio-reporting rain gages on the main stem basin and automatic stream gages on the North Fork (Alternative 6).

The basin-scale alternatives include:

- Volunteer stream gage observers (Alternative 7).

- Automatic radio-reporting stream gages (Alternative 8).

- Volunteer rain gage observers (Alternative 9).

- Automatic radio-reporting rain gages (Alternative 10).

- Radar receiver at Fort Collins to obtain radar view from Cheyenne NWS radar by means of dedicated phone line (Alternative 11).

- Private meteorological consulting firm retained to give detailed forecasts for Larimer County area (Alternative 12).

The volunteer observers have voice radio, indoor recording rain gages, or staff gages for determining stream level. Volunteer radios would require a tone-alert pager for each observer, repeaters, and a base station voice radio. Automatic radio gages would require repeaters and a base station data receiver, minicomputer, and printer.

COMPONENTS OF ALTERNATIVES

Table 16 displays the component parts of each flash flood detection alternative.

COST OF ALTERNATIVES

The costs of the flash flood detection alternatives are summarized in tables 17 and 18. A base station was assumed to be located in existing facilities at Fort Collins with no additional cost. Charts or graphs for relating streamflow to rainfall and rating curves for computing stream discharge from stage data were considered to be supplied to local interests by Federal or State assistance. Costs do not include time spent by field observers. Field operating costs are only for maintaining equipment. Price levels are as of September 1980. Alternatives utilizing automatic devices located in the field would be susceptible to vandalism. For example, if one automatic rain gage or stream gage per year must be replaced in alternatives 2, 3, 5A through 6, 8, and 10, annual operation and maintenance costs would increase by 30 to 100 percent. Only the minimum number of radio relays or repeater towers necessary to operate the alternatives were included in costs. A Law Enforcement Assistance Administration (LEAA) - assisted by radio network is planned for Larimer County. It was presumed this network

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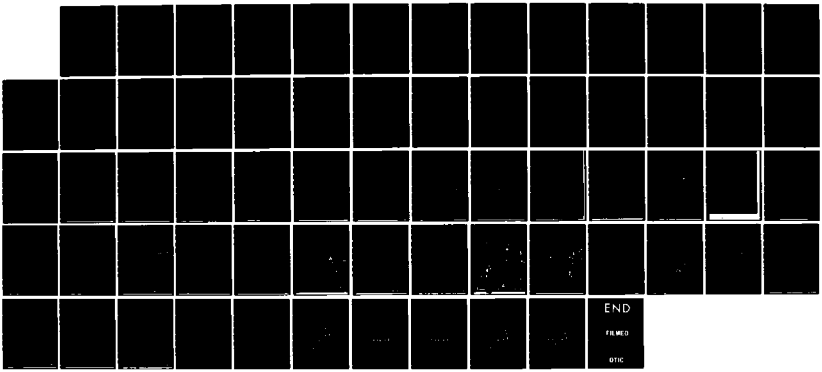

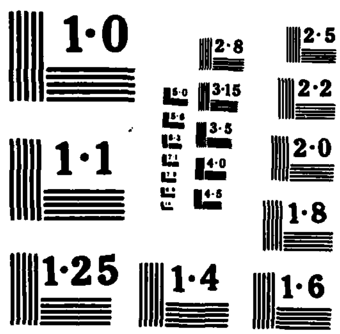
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Table 16
Components of
Flash Flood Detection Alternatives

Components	Minimum-Scale			Intermediate-Scale							Basin-Scale					
	Vol.(1)	Mix.(2)	Auto.(3)	Vol.(1)	Mix.(2)					Auto.(3)	Vol.(1)	Auto.(3)	Vol.(1)	Auto.(3)	Cent.(4)	Cent.(4)
PLAN NO.	1	2	3	4	5A	5B	5C	5D	5E	6	7	8	9	10	11	12
Volunteer rain gages	10	7	-	21	7	-	21	-	-	-	-	-	38	-	-	-
Volunteer staff gages	8	6	-	9	6	9	-	8	8	-	12	-	-	-	-	-
Volunteer radios	12	7	-	23	7	9	21	8	8	-	12	-	38	-	-	-
Automatic rain gages	-	3	8	-	11	16	-	-	16	16	-	-	-	34	-	-
Automatic stream gages	-	1	2	-	2	-	8	8	3	3	-	9	-	-	-	-
Repeater stations	2	2	1	2	2	2	2	2	2	1	2	1	2	1	-	-
Base station																
Voice radio	1	1	-	1	1	1	1	1	1	-	1	-	1	-	-	-
Minicomputer & printer	-	1	1	-	1	1	1	1	1	1	-	1	-	1	-	-
Radar receiver	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Weather consultant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Coordinator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

1 Vol. = Volunteer field observations

2 Mix. = Mixed volunteer and automated field observations

3 Auto. = Automated field observations

4 Cent. = County - sponsored operations only at emergency operations center

Table 17
Estimated First Cost of Flash Flood Detection Alternatives

Alternative	Field Equipment	Base Station Equipment	Subtotal	Total Including 25 Percent Contingencies
Minimum-Scale				
1. (Vol.)	$ 52,200	$ 3,000	$ 55,200	$ 70,000
2. (Mix.)	55,050	15,000	70,050	90,000
3. (Auto.)	45,000	12,000	57,000	70,000
Intermediate Scale				
4. (Vol.)	80,550	3,000	83,550	105,000
5A. (Mix.)	88,050	15,000	103,050	130,000
5B. (Mix.)	93,850	15,000	108,850	135,000
5C. (Mix.)	105,450	15,000	120,450	150,000
5D. (Mix.)	75,200	15,000	90,200	115,000
5E. (Mix.)	106,200	15,000	121,200	150,000
6. (Auto.)	78,000	12,000	90,000	115,000
Basin Scale				
7. (Vol.)	45,800	3,000	48,800	60,000
8. (Auto.)	52,000	12,000	64,000	80,000
9. (Vol.)	107,100	3,000	110,100	140,000
10. (Auto.)	126,000	12,000	138,000	175,000
11. (Cent.)	0	30,000	30,000	40,000
12. (Cent.)	0	0	0	0

Table 18
Operation, Maintenance, and Replacement Costs of Flash Flood Detection Alternatives

Alternative	Operation and Maintenance					Total
	Field Equipment	Base Station Equipment	Meteorological Consultant	Coordinator	Subtotal	Operation, Maintenance, and Replacement
Minimum-Scale						
1. (Vol.)	$2,380	$100	$ -	$12,000	$14,480	$16,100
2. (Mix.)	2,770	500	-	12,000	15,270	17,300
3. (Auto.)	2,600	400	-	12,000	15,000	16,600
Intermediate-Scale						
4. (Vol.)	3,690	100	-	12,000	15,790	18,200
5A. (Mix.)	4,770	500	-	12,000	17,270	20,200
5B. (Mix.)	4,860	500	-	12,000	17,360	20,400
5C. (Mix.)	5,910	500	-	12,000	18,410	21,800
5D. (Mix.)	4,720	500	-	12,000	17,220	19,800
5E. (Mix.)	5,920	500	-	12,000	18,420	21,800
6. (Auto.)	4,600	400	-	12,000	17,000	19,600
Basin-Scale						
7. (Vol.)	2,080	100	-	12,000	14,180	15,500
8. (Auto.)	3,800	400	-	12,000	16,200	18,000
9. (Vol.)	4,580	100	-	12,000	16,680	19,900
10. (Auto.)	7,000	400	-	12,000	19,400	23,400
11. (Cent.)	0	800	-	9,000	9,800	10,700
12. (Cent.)	0	0	1,800	9,000	10,800	10,800

could be used as an alternative radio transmission route in case of damage to the flood detection system repeaters.

Annual costs and replacement costs were calculated using a 7.375 percent interest rate and a 50-year period of economic analysis. All equipment was replaced at the end of each 20-year period, with no salvage value. Replacement costs were converted to present worth and amortized at 7.375 percent over the 50-year period of economic analysis.

DAM BREAK AND SNOWMELT DETECTION

Larimer County officials expressed a concern about detection of dam failure and snowmelt floods. The area of concern is to the west of the cloudburst zone that would be covered by the flash flood detection alternatives. One possible alternative would be a radio-reporting float type stream gage in the pool area of each dam and another gage downstream from each dam. This would require eight gages for the four significant dams upstream from Spencer Heights. Another alternative would be a stream gage on Joe Wright Creek about 6 miles upstream from Spencer Heights. This gage would detect runoff from Joe Wright, Chambers Lake, and Barnes Meadow Reservoirs. Another gage could be located downstream from Long Draw Reservoir on the main stem of the Cache la Poudre River. To provide redundancy there should be a total of 4 gages. The lowest cost alternative would be a stream gage on the Cache la Poudre River about 3 miles upstream from Spencer Heights just downstream from the confluence of Joe Wright Creek with the Cache la Poudre River. This alternative was used in table 20. The equipment for this alternative would be located near Colorado Highway 14, an all-weather highway. The equipment could thus be more readily maintained throughout the year. To provide redundancy, two gages should be used. It is also estimated that two repeaters would be needed to join up with the flash warning radio network. A voice radio

and pager should be located in the Spencer Heights area. The estimated minimum cost for adding dam failure detection is given in table 19. This cost is separate from the costs used in the analysis of flash flood detection systems.

Table 19
Estimated Cost
Of Dam Failure and Snowmelt Detection

Item	Amount
First Cost	
Automatic stream gages	$10,000
Repeater stations	14,000
Voice radio	1,250
Total first cost	$25,250
Total cost w/25% contingencies	$30,000
Operation and maintenance	$ 1,240
Operation, maintenance and replacement	$ 1,900

EVALUATION

As stated previously, the objective of the flash flood detection alternatives is to provide as much lead time as possible at as low a cost as possible, consistent with performance.

It is expected that the NWS forecasting system will detect most flood producing conditions. The flash flood detection alternatives should provide a backup to the NWS. In order to do this, an alternative should provide Larimer County officials with a positive warning of flash floods in the absence of NWS radar, or a forecast from the NWS or the private weather consultant. Such a situation could arise if a localized fast-forming storm occurred when the Cheyenne radar happened to be turned off; the Limon radar is too far away to detect such an event properly. NWS personnel could also be occupied with severe

weather in other parts of Colorado. Volunteer reports received might also be insufficient to predict severity of flooding.

INITIAL SCREENING

The minimum-scale alternatives 1, 2, and 3 would be an improvement over the existing situation. The cost analysis indicates that to achieve at least a worthwhile degree of detection, as represented by these alternatives, an investment of about half of that for the intermediate-level alternatives would be required. However, a somewhat greater number of sensors would be desirable and the minimum-scale alternatives would not provide a redundant means of data collection.

The basin-scale flash flood detection alternatives are 7, 8, 9, 10, 11, and 12. These are single-component alternatives and provide no redundancy. Also, coverage of the upper North Fork basin would be excessive as the North Fork runoff is relatively slow and the area is sparsely populated. Alternative 11, with a color radar receiver at Fort Collins, while helpful, would not be independent of the NWS radar and would, therefore, not provide backup. Ground confirmation of the rainfall indicated by radar would also be needed. Alternative 12 involves employing a private meteorological consultant. The odds of a successful forecast might be improved because a consultant could focus on the specific area of concern to a client; the NWS forecasters are responsible for 29 counties in Colorado. For example, during the 1979 cooperative flood warning program at Denver, on 13 of 16 significant flash flood potential days, severe weather in parts of Colorado away from the Denver area demanded warning action by NWS forecasters.[22] The private forecasts should be coordinated with the NWS. However, the flash flood detection alternatives, to provide redundancy, should give warning independent of forecasts.

The intermediate-scale alternatives shown on plates 13 through 18 were selected for further evaluation.

COMPARISON OF ALTERNATIVES

Table 20 presents comparative data for the flash flood detection alternatives. Alternative 4 would include an all-volunteer network of rain and stream gage observers. Alternative 5A would include volunteer rain and stream gage observers along the main stem and automatic equipment in remote areas. Alternative 5B would use automatic rain gages and volunteer stream staff gage observers. However, because rain gages would be confined to the main stem basin only volunteer staff gages would be on the North Fork. To provide redundancy on the North Fork, alternative 5B was eliminated and replaced by alternative 5E by adding automatic stream gages along the lower reach of the North Fork. Alternative 5C would use volunteer rain gage observers and automatic stream gages. Alternative 5D would consist of an automatic stream gage network and a backup volunteer staff gage network. Alternative 6 would use completely automatic sensors: a rain gage network in the main stem basin and stream gages on the North Fork.

The first and annual costs shown in table 20 indicate that the six alternatives would require about the same level of investment. Except for the stream gage alternative, 5D, all would provide similar lead time for flash flood warning. Lead times indicated should be taken as approximations because different results could be obtained with different hydrologic models, storm locations, or rainfall distributions. For predictions based on rainfall lead time is defined as the interval from 15 minutes into heavy rain to the time of approximate bankful discharge with 20 minutes deducted for data transmission and interpretation. For alternative 5D, lead time is defined as the interval from the occurrence of flood stage at an upstream gage to the time of flood stage at the point to be warned, with 10 minutes deducted for data interpretation.

Visual verification of flooding would provide more confidence in warnings. Only the automatic alternative, 6, would not provide this. Confirmation of rainfall indicated by the NWS radar could be provided by all alternatives except 5D. Volunteer radios in the main stem valley

Table 20
Comparison of
Flash Flood Detection Alternatives

Item	Alternative 4	5A	5C	5D	5E	6
Components	VR,VS	VR,VS,AR,AS	VR,AS	VS,AS	AR,VS,AS	AR,AS
Lead time (hours:minutes)						
At Poudre Park						
Storm centered at Rustic	3:00	3:00	3:00	2:15	3:00	3:00
Storm centered 5 miles U/S Poudre Park	1:10	1:10	1:10	0:25	1:10	1:10
At Fort Collins						
Storm centered at Rustic	6:15	6:15	6:15	5:10	6:15	6:15
Storm centered at Poudre Park	4:05	4:05	4:05	3:00	4:05	4:05
Storm U/S Halligan Reservoir	4:20	4:20	4:20	3:50	3:50	4:20
Storm D/S Halligan Reservoir	2:50	2:50	2:50	2:50	2:50	2:50
Visual verification of flash flood in stream	Yes	Yes	Partial (from rain observers)	Yes	Yes	No
Provide confirmation of radar rainfall estimates	Yes	Yes	Yes	No	Yes	Yes
Provide aid in dissemination of warning	Yes	Yes	Yes	Yes	Yes	No
Number of independent detection networks	2	2	2	2	2	1
Number of detection networks including (1) NWS radar and (2) private spotters	4	4	4	4	4	3

Table 20 (Cont'd)
Comparison of
Flash Flood Detection Alternatives

Item	Alternative 4	5A	5C	5D	5E	6
Reliability	Affected by number of volunteers away or asleep and maintenance of gages and radios	Affected by readiness of volunteers on main stem.	Early detection affected by readiness of volunteers. Verification if stream gages operate.	Stream gages regarded as more reliable than rain gages. Verification affected by volunteer readiness.	Early detection affected by rain gage and radio functioning. Verification affected by volunteer readiness.	Dependent on proper gage and radio relay function. No backup network.
Credibility	Credible if sufficient volunteers give timely reports	Credible if sufficient volunteers report and confirm automatic equipment.	Credible. Lead time inadequate if only automatic stream gages report.	Credible, but lead time too short for storms near hazard site. Stream gages more positive flood indicator than rain gages.	Credible. Lead time inadequate if rain gages do not report.	Credible if gages report. However, no visual verification provided.
Operation	Volunteer rain and stream observers report by radio.	Volunteer observers on main stem report by radio. Automatic equipment in remote areas.	Volunteer rain observers report by radio. Automatic stream gages verify flood.	Volunteer and automatic stream gages report by radio. No rain gages.	Automatic rain gages report rain. Verified by volunteer stream observers.	Automatic rain gages in main stem watershed. Automatic stream gages on North Fork.

Table 20 (Cont'd)
Comparison of
Flash Flood Detection Alternatives

Item	Alternative 4	5A	5C	5D	5E	6
Automatic field sensors required	0	13	8	8	19	19
Field personnel required for detection	23	7	21	8	8	0
First cost	$105,000	$130,000	$150,000	$115,000	$150,000	$115,000
Annual operation, maintenance, and replacement costs	$ 18,200	$ 20,200	$ 21,800	$ 19,800	$ 21,800	$ 19,600
Total annual costs	$ 26,200	$ 30,100	$ 33,200	$ 28,500	$ 33,200	28,300

A = Automatic, V = Volunteer, R = Rain gage, S = Stream gage

would provide a means of disseminating warning in addition to serving for flood detection. Only alternative 6 would not provide this capability. Alternative 6 would have only one detection network, while the others would provide two alternative means of flood detection.

RELIABILITY AND CREDIBILITY

If cost and lead time are not sufficient criteria, selection of an alternative may have to be made on the basis of other performance criteria. The report made for the Boulder flood warning plan(25) evaluated alternatives using criteria such as reliability, credibility, non-flood warning benefits, implementation, and flexibility. Reliability and credibility were used in this report. Reliability is defined as the dependability of operation of a warning system's component parts. Credibility is defined as the certainty of prediction of a flood. Low credibility warnings produce excessive numbers of false alarms or actually miss flood events.

It is difficult to compare reliability and credibility of flash flood detection alternatives with mixed methods of observation. Rather than to assign subjective ratings to each alternative, such as "fair" or "good", the advantages and disadvantages of components of the alternatives are outlined.

Those alternatives involving volunteer rain and stream gages are dependent on the readiness of observers. At the time of a storm, some may be away or asleep. Maintenance of the rain gages and radios is also a factor. For example, although the rain gage would be an indoor recording type, a paper roll would need to be replaced every 30 days. The degree of interest affects the readiness of a volunteer network. In areas such as the Susquehanna River basin, the frequency of floods helps to maintain interest in volunteer warning networks. (Telephone conversation with Mr. Stewart K. Wright, Susquehanna River Basin Commission, 31 October 1979). In the Cache la Poudre River basin area, however, there have been long intervals between major rainfall floods,

although the annual spring rise from snowmelt attracts some public attention. Staff gages would be located at or a short drive from observer residences. Although binoculars and a spotlight would be provided, heavy rain may reduce visibility such that the gage cannot be read. Although qualitative data about river levels could be reported, the promptness of reports might vary from one observer to another. The location of potential observers was determined by field observation or by points where residences were indicated on USGS quadrangle maps. If it develops that there are no longer residents at some of these locations, the observer network would not be dense enough.

There are some advantages to visual observer reports. These reports are probably more believable than automatic reports, thereby inspiring more confidence to take action. Volunteer observers can give qualitative data in addition to rainfall amounts, such as wind speed, lightning intensity, and changing storm conditions.

The electronic operation of the automatic rain gages and stream gages is presumed to be reliable. Station operational condition would be reported at least daily and replacement would presumably be made. Automatic gages are susceptible to vandalism. The automatic rain gages would be of the tipping bucket type; to register rainfall accurately, they must be installed so the bucket device is level. If rain gages are left out all year, an antifreeze solution is needed to melt snow so it can be registered on a gage. In a major flood, the stream gages may be destroyed and would have to be replaced. The reliability of gages is affected by maintenance. The usefulness of the NWS flash flood alarm stream gages, which report by telephone, has been variable; it depends on the degree of local interest and gage maintenance. (Telephone conversation with Mr. Ken King, National Weather Service River Forecast Center, Kansas City, 7 December 1979).

20. Henz, J.F., "Successes and Problems Encountered in Predicting Flash Flood Potential in Both Urban and Foothills Locales," Preprints, Second Conference on Flash Floods (Atlanta), American Meteorological Society, Mar. 1980. pp. 155-160.

21. Henz, J.F. 1980

22. Henz, J.F. 1980

23. King, J.F., Newton, D.W., and Pearson, H.S., "Gatlinburg, Tennessee, Flood warning and Evacuation System," Preprints, Second Conference on Flash Floods (Atlanta), American Meteorological Society, Mar. 1980, pp. 205-212.

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APPENDIX B

REFERENCES

Spillway

A passage for surplus water to run over or around a dam. Floods which cannot be contained in the pool behind the dam are passed through the spillway to avoid overtopping of the embankment. Most dams in the Cache la Poudre River basin have a spillway in the form of an earth-cut channel off to the side of the dam.

Standard Project Flood (SPF)

The flood that may be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. Peak discharges for these floods are generally about 40 percent to 60 percent of the Probable Maximum Floods for the same basins. Such floods, as used by the Corps of Engineers, are intended as practicable expressions of the degree of protection that should be sought in the design of flood control works, the failure of which might be disastrous.

Stilling Basin

Usually a concrete or riprap basin at the downstream end of an outlet works or spillway to allow dissipation of the energy of a high speed discharge of water, so that excessive turbulence does not damage the channel downstream.

Surcharge Storage

In this report, this refers to the volume of storage available between the normal pool and the top of a dam. If there is a spillway, some spill will also occur in the surcharge zone.

Telemetry

Observations made by remote instruments and transmitted by radio to a receiving station.

Tipping-Bucket Rain Gage

A rain gage which measures rain in increments by means of a small divided bucket. As rain fills one side, it tips and empties as the other side is moved into position to be filled. The device can be designed to tip after a particular increment of rainfall. Each tip can result in an electrical signal to indicate the rainfall. The rainfall data can be transmitted to a minicomputer to be stored, displayed, or analyzed.

Visible Images

In this report, this refers to images sent by satellite showing the earth as seen by the human eye, in wavelengths of visible light. Visible images, combined with infrared images, are used in one method of estimating rainfall from cloud types observed by satellite.

Radar Receiver

In this report, a monitor screen which can display the picture seen on a radar located elsewhere. This may be a color TV screen with accessory controls which can pick up the signal from the radar through a dedicated telephone line.

Radar Reflectivity

The strength of the radar echo or signal bounced back to the radar station. Weather radar emits frequencies such that rainfall or clouds will be detected, rather than solid objects such as aircraft. The more intense the echo (shown on a screen), the heavier the rainfall.

Redundancy

Having an alternate or back-up means of accomplishing an objective if the primary method fails.

Repeater

A radio transmitter on a tower that can relay a radio signal from another transmitter to a receiving station. In mountainous areas, the other transmitter may not be able to reach the receiving station directly.

Runoff

The quantity of rainfall which flows over the surface to enter the stream as discharge volume. The difference in quantity between rainfall and runoff represents losses to infiltration and interception.

Size Classification of Dams

In the NDSP dam inspection reports, an "intermediate" size dam has a height equal to or greater than 40 feet but less than 100 feet, and a storage capacity equal to or greater than 1,000 acre-feet, but less than 50,000 acre-feet. Dams below these limits are termed "small" and those above "large." Size is determined by storage or height, whichever results in the larger size category.

Software

The computer programs or sets of instructions that tell a computer what to do. Hardware refers to the physical equipment that make up a computer system, such as the computer itself, input keyboards, printers, or display screens.

Soil Infiltration Capacity

The ability of a soil to absorb rainfall. For example, sandy soils may absorb a great deal of rainfall without leaving an excess for surface runoff. This may refer to the total proportion of rainfall absorbed or to a rate in inches per hour (see "Runoff").

Left (or right)

Refers to the observer's left or right while facing downstream. For example, the "right bank" or the "left abutment".

Offstream

Refers to dams located away from a natural stream, such as a dam located in a normally dry gulch. In the Cache la Poudre River basin, these dams are usually furnished with water by irrigation canals.

Outlet Works

Usually a conduit with related structures through a dam embankment through which controlled releases of water from a reservoir can be made.

Pagers

A radio device that gives off a tone to alert the receiver to take action.

Peak Discharge

The maximum instantaneous discharge of a flood at a given location. It usually occurs at or near the time of the flood crest.

Peaking Time

The time from flood-producing rainfall (see "Runoff") to the time the flood reaches its maximum discharge.

Probability

The annual chance of occurrence of specific hydrologic events, such as rainfall over a specified area or peak discharge at a specified location expressed in percent, e.g., 5 percent representing one chance in 20 of the event occurring in any year.

The 10-, 50-, 100-, and 500-Year Floods

Floods having a 10, 2, 1, or .2 percent probability, respectively, of occurrence in any year or an average frequency of occurrence in the order of once in 10, 50, 100, or 500 years, respectively. The flood may occur in any year. It is based on statistical analyses of streamflow records and analyses of rainfall and runoff characteristics in the general region of the watershed.

Probable Maximum Flood (PMF)

The most severe flood which can result from the most critical combination of circumstances reasonably possible for the area in which the drainage basin is located. Probable maximum precipitation (PMP) amounts are used to derive the spillway design flood for large dams to insure their safety against even a remote possibility of failure. The PMP is generally available from the National Weather Service.

Gradient

In this report, this usually refers to the slope of a streambed in the downstream direction. This may be expressed in feet per mile or in feet per foot.

Hazard Classification of Dams

Classification according to degree of loss of life or economic loss that would potentially result from failure of the dam. It does not necessarilly reflect the likelihood of failure.

Hydrograph

In this report, this refers to a graph or table showing the variation of discharge over a period of time at a given location. A flood hydrograph would show a rise in discharge, a peak, and then a decrease in discharge, gradually returning to normal levels. The time scale for a rainfall flood might be in hours, while for a snowmelt flood, it would be days or weeks.

Hydrologic Capability

In the NDSP dam inspection reports, dams which cannot pass a flood 50 percent of the magnitude of the Probable Maximum Flood (see definition) without overtopping are termed "seriously inadequate." Those which can pass the PMF without overtopping are termed "adequate." Those passing between 50 and 100 percent are termed "inadequate."

Hydrologic Model

A computer program which takes into account factors affecting the relationship between rainfall and runoff and makes estimates of stream discharge based on rainfall and physical characteristics of the area involved.

Hydrologic Studies

In this report, this generally refers to studies to determine the discharge-probability relationship at various locations or to determine Probable Maximum Flood hydrographs at dam sites to evaluate the hydrologic capability of the dams.

Infrared Images

Images made by detectors sensitive to thermal radiation at wavelengths longer than those of visible light. Such images would show objects colored or shaded according to their temperature.

Intake Structure

The gated tower or other structure at the upstream end of an outlet works where water is allowed to drain out of a reservoir into the outlet works conduit.

Discharge-Probability Relationship

The chances (see "Probability") of floods of different magnitude occurring at a given location. Smaller floods are likely to occur more often, while greater floods are less common.

Encroachments

Structures or activities which enter the flood plain and occupy it. For example, buildings which may be subject to flood damage, or artificial fill which could block flood flows and increase flood levels.

Event-Reporting

Instruments that report data as certain events occur. For example, rain gages that report each 0.1 inch of rain. This is in contrast to instruments that report at regular time intervals, such as every 15 minutes, regardless of whether anything has occurred.

Facsimile

In this report, this refers to a printed reproduction on paper of a radar scope image, transmitted by wire from a radar site.

Flood Boundaries

The outer limits of the flooded area for a particular flood, as seen on an aerial photo or a map. The flood may be an assumed flood of a given discharge or a given chance of occurrence. It may also be drawn for a flood that has already taken place.

Flood Crest

The maximum stage or elevation reached by the waters of a flood at a given location.

Flood Hazard Areas

Generally refers to the area subject to floods up to some specified magnitude. In this report, it refers also to areas of population concentration in the Cache la Poudre River canyon.

Flood Plain

The relatively flat area or low lands adjoining the channel of a river, stream, water course, ocean, lake, or other body of standing water which has been or may be covered by floodwater.

Frequency

(See Probability)

Gate Structures

In this report, this refers to the gates which are closed or opened within the outlet works at a dam to release water from the reservoir. This may be done for irrigation purposes or to dry the reservoir for maintenance.

APPENDIX A

GLOSSARY

Abutment

The end of a dam embankment where it meets the natural ground at the side of a valley.

Average Annual Damages

The summation of the flood damages of all the floods that could occur during any given year to obtain an average annual flood damage. Each flood would contribute to the total annual damage according to its magnitude and its likelihood of occurrence. For example, a flood with a one-percent chance of occurrence during the year and causing $1,000,000 damage, would contribute $1,000,000 x 0.01 = $10,000 to the average annual damage.

Depth-Discharge Relationship

A known relationship (sometimes called a "rating curve") between depth and stream discharge at a stream gage. The discharge at the gage can be determined by reading the stage or water level at the gage.

Dial-Up

Obtaining a connection or access to remote electronic equipment, such as radar, by phone. This line is shared with other users. Better service may be obtained by a "dedicated" line which would not be shared with others.

APPENDIX A

GLOSSARY

Additional reliability could be obtained by adding more observation networks to each alternative. Table 21, however, indicates that alternatives 5A through 5E would result in four alternative means of flash flood detection, if NWS forecasts and potential private spotter networks are taken into account.

SELECTION

Successful operation of a flash flood detection network is dependent on local interest and resources. Therefore, in the selection of an alternative, Larimer County officials were asked to comment on alternatives 4 through 6. Comments were also solicited from the NWS, the Colorado Water Conservation Board, the U.S. Forest Service, and from personnel operating the existing flood warning system in Boulder County.

CONCLUSIONS

Larimer County has taken initial action on flood warning by employing a private weather consultant with a rainfall spotter network and a color radar receiver. Local officials are not ready at this time to select a more extensive flood warning system.

RECOMMENDATIONS

A flood warning system should be developed consistent with the needs and resources of the area. Equipment for the flood warning system should be carefully selected to insure reliable operation and reasonably convenient maintenance. It is recommended that this report be published for the information of local interests.

Early detection in alternative 5C would be dependent on the reliability of the volunteer rain gage network, as is true of alternative 4. The automatic stream gages would set off a more definite flood alarm as flooding entered the major streams. Visual verification of stream flows could come from some rain observers, although without staff gages, they would have no specific stream levels to report.

Alternative 5D, with only stream gages, would not provide sufficient lead time for areas close to rain storms. If NWS radar is operating, 5D could not provide confirmation of rainfall intensities.

Alternative 5E would provide early warning with automatic rain gages serving the main stem and automatic stream gages on the North Fork. There is the possibility that, in practice, local officials might hesitate to issue a warning based on rainfall and would wait for confirmation by a stream gage.

Alternative 6, with a completely automatic network, would not provide a backup means of flood detection. There would be no capability for visual verification of flooding or for assistance in warning dissemination.

Assuming the absence of external assistance from the NWS or a spotter network, alternative 5E is tentatively recommended. It would provide the earliest warning of a reasonably definite nature. Alternative 5E also would provide visual verification of flooding and a method to aid warning dissemination.

If a reliable rainfall spotter network can be implemented to provide early alerts, alternative 5D would provide very credible verification of flooding.

In general, rain gages provide quicker identification of flash floods than stream gages. Stream gages provide a more definite warning as they record flows actually in the river. For rain gages, data interpretation may be more difficult, as the relationship between rain and resultant runoff needs to be established. Stream gages may not provide enough lead time. If the gages are spaced far enough upstream to provide sufficient lead time, rainfall downstream from the gage could cause higher flooding than expected. For the alternatives in this report, there are larger numbers of rain gages than stream gages, so the loss of a rain gage would seem less serious than the loss of a stream gage.

The reliability of all the flash flood detection alternatives is dependent on radio. It is presumed that for each alternative, Larimer County's planned radio network could provide an alternative radio transmission route. If not, the entire alternative might be rendered inoperative if a single repeater station malfunctioned because of wind damage, vandalism, lightning, or other factors.

SUMMARY

The volunteer network in alternative 4 would have gaps in the designed network if there were absences or a lack of readiness. Many areas are populated too sparsely to add substitute observers. With inadequate reports, the network may not be able to indicate more than "heavy rain". In that case, a lower cost, less formal volunteer network would serve as well.

Alternative 5A would be dependent on the readiness of volunteers along the main stream. The two separate networks, automatic and volunteer, would serve different geographic areas and so would not provide redundancy.

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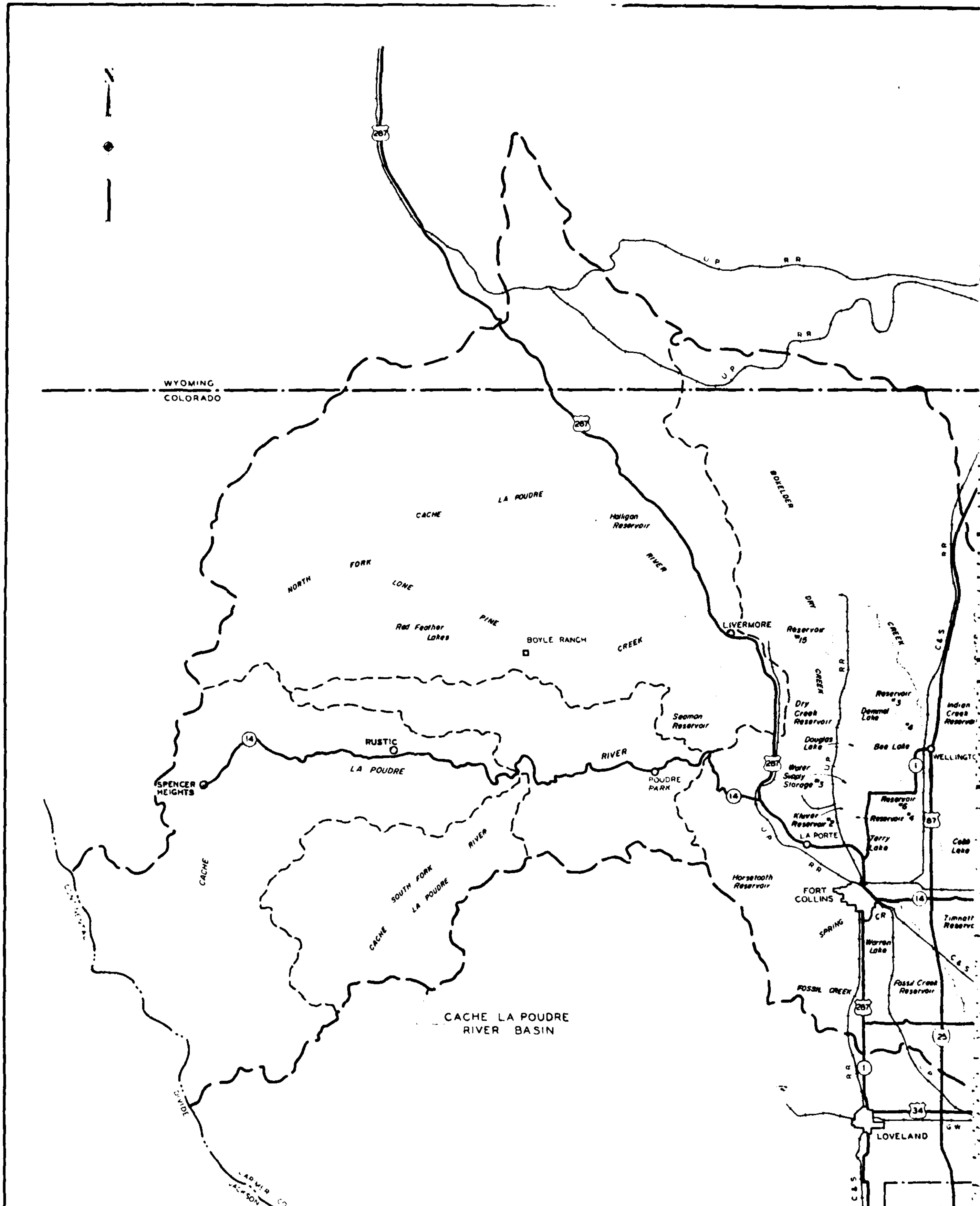
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Red Feather Lakes
BOYLE RANCH
LIVERMORE
DRY CREEK
Reservoir #15
Dry Creek Reservoir
Douglas Lake
Water Supply Storage #3
Seaman Reservoir
RUSTIC
LA POUDRE RIVER
SPENCER HEIGHTS
POUDRE PARK
Reservoir #3
Demmel Lake
Bee Lake
Indian Creek Reservoir
WELLINGTON
Reservoir #6
Reservoir #4
Klaver Reservoir #2
LA PORTE
Terry Lake
Cobb Lake
Horsetooth Reservoir
FORT COLLINS
SPRING CR
Warren Lake
Timnath Reservoir
FOSSIL CREEK
Fossil Creek Reservoir
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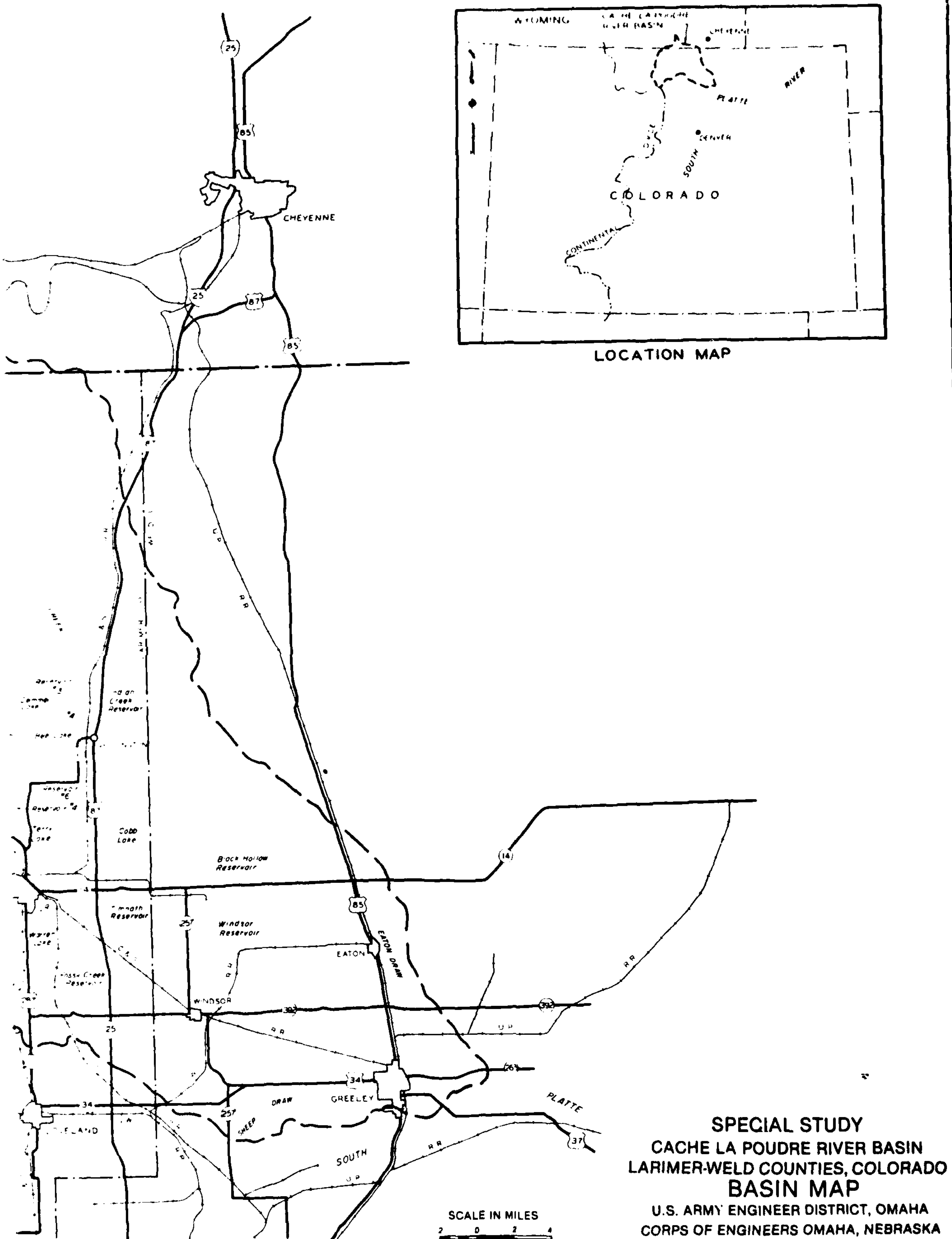

SPECIAL STUDY
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO
BASIN MAP
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

VOLUME I **PLATE 1**

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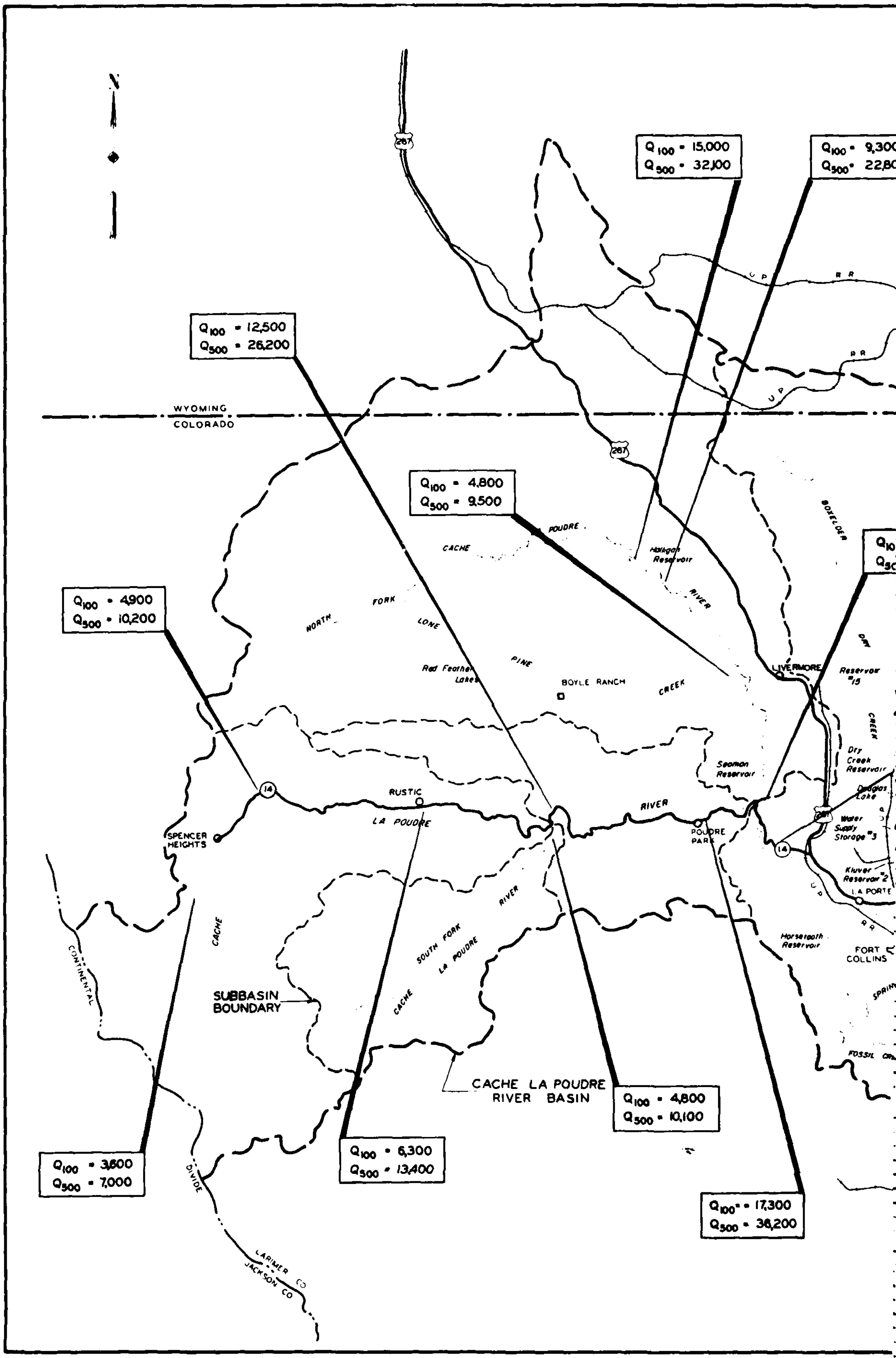
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Halligan Reservoir
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NORTH FORK
LONE PINE CREEK
Red Feather Lakes
BOYLE RANCH
LIVERMORE
Reservoir #15
DRY CREEK
Dry Creek Reservoir
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Water Supply Storage #3
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RUSTIC
SPENCER HEIGHTS
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POUDRE PARK
Horsetooth Reservoir
FORT COLLINS
SPRING
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CACHE
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JACKSON CO
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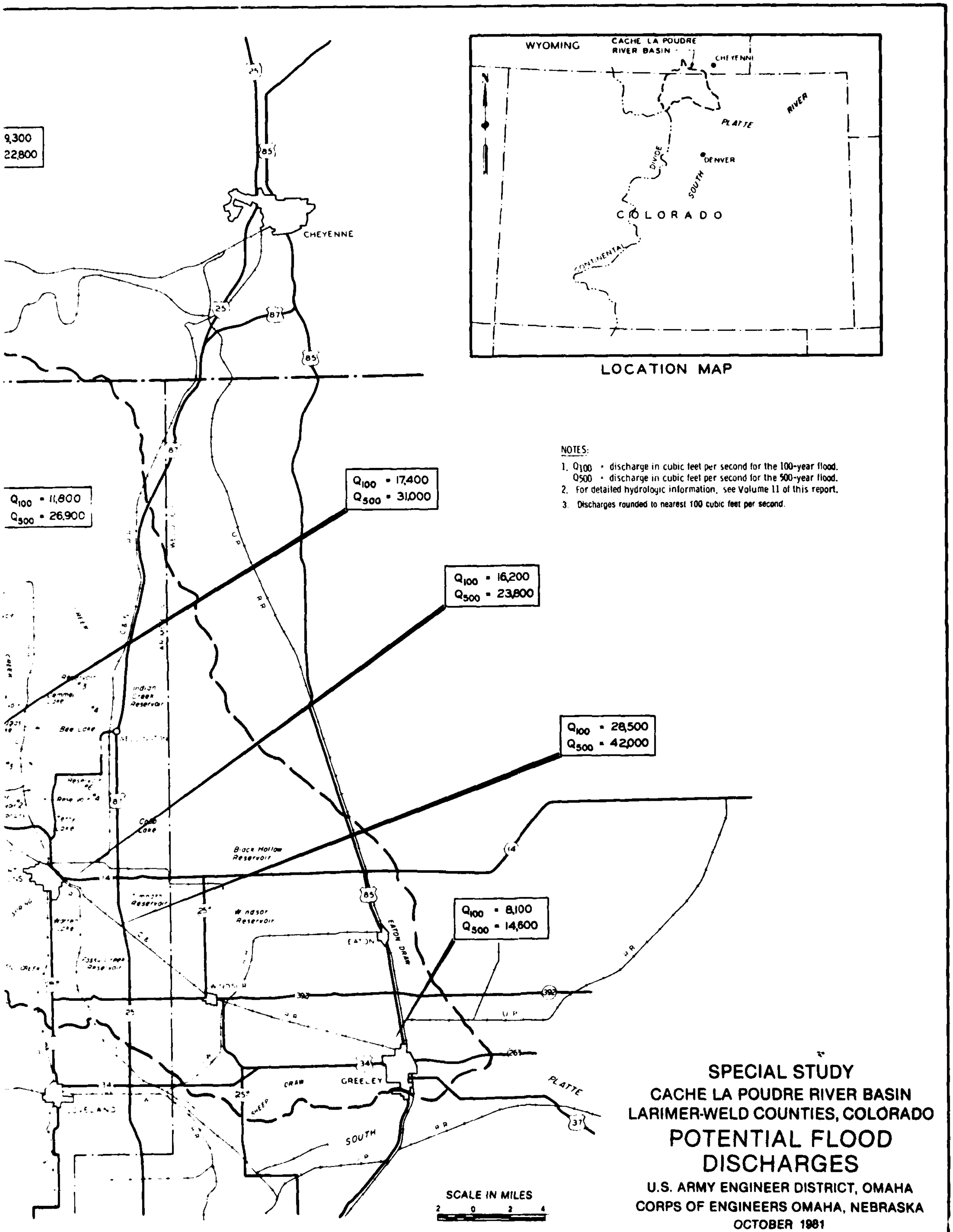

NOTES:
1. Q_{100} = discharge in cubic feet per second for the 100-year flood.
   Q_{500} = discharge in cubic feet per second for the 500-year flood.
2. For detailed hydrologic information, see Volume II of this report.
3. Discharges rounded to nearest 100 cubic feet per second.

SPECIAL STUDY
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

POTENTIAL FLOOD DISCHARGES

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

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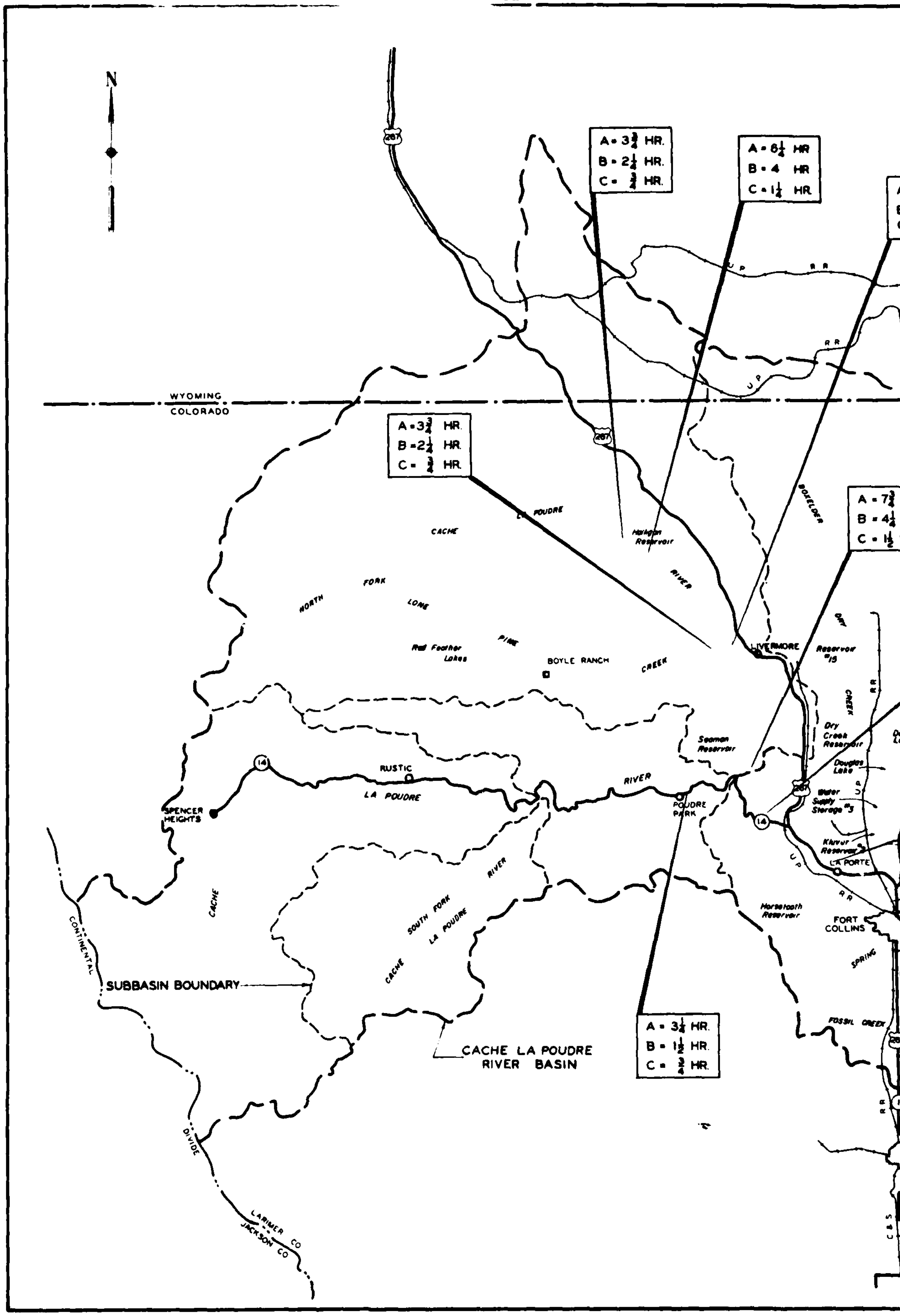
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A = 3¾ HR.
B = 2¼ HR.
C = ¾ HR.
A = 6¼ HR
B = 4 HR
C = 1¼ HR
A = 7¾ H
B = 4¼ H
C = 1½ H
A = 3¼ HR.
B = 1½ HR.
C = ¾ HR.
WYOMING
COLORADO
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BOXELDER
CACHE LA POUDRE RIVER
NORTH FORK LONE PINE CREEK
Halligan Reservoir
Red Feather Lakes
BOYLE RANCH
LIVERMORE
Reservoir #15
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CACHE LA POUDRE SOUTH FORK RIVER
Horsetooth Reservoir
FORT COLLINS
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SUBBASIN BOUNDARY
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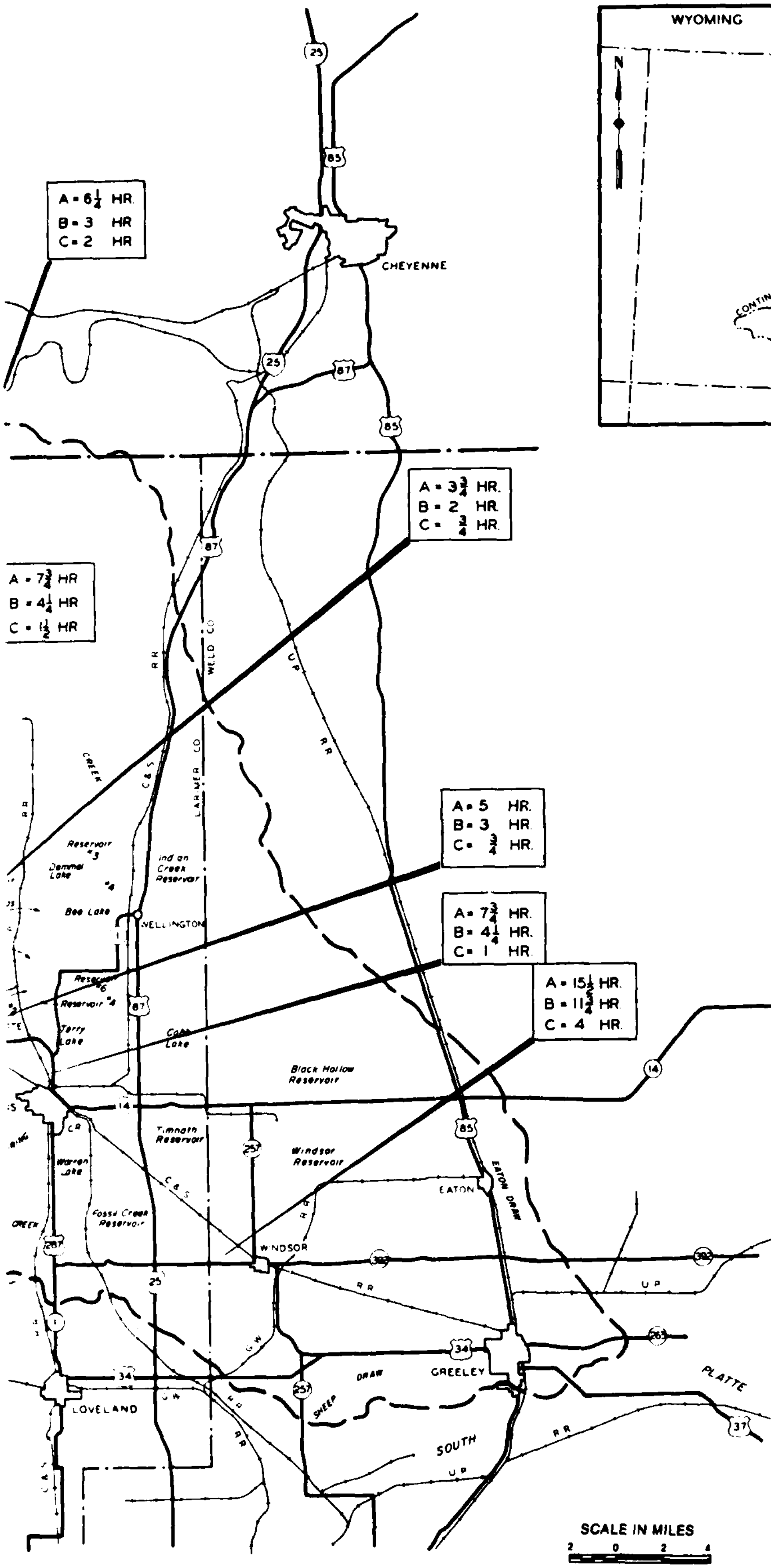

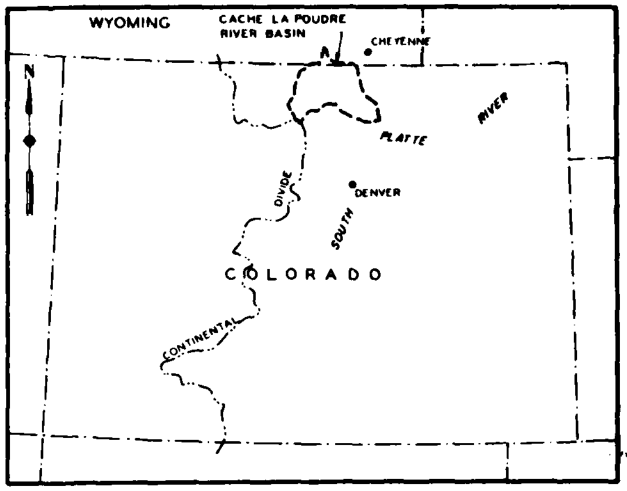

LOCATION MAP

LEGEND:

A - Time from 15 minutes into heavy rainfall to peak discharge

B - Time from 15 minutes into heavy rainfall to time of 5000 CFS discharge on major streams or 2500 CFS on major tributaries. For this study, these discharges were selected to represent the threshold of significant flooding.

C - Time from noticeable rise in stream flow at the designated location (defined as 1000 CFS on major streams or 500 CFS on major tributaries) to threshold of significant flooding.

NOTES:

1. The 100-year flood is used as a representative flood for the illustration of runoff time. In the mountain area (upstream from the confluence of the Cache la Poudre River with the North Fork, Cache la Poudre River)rainfall is assumed to cover the entire area above each designated location. The flood in the plains is assumed to originate on the main stem, which has more rapid runoff than the North Fork. Timing of flood runoff in the plains is computed by determining the timing at the North Fork confluence and adding to this the travel time of floods through the plains reaches. No rainfall is assumed in the plains.
2. Runoff time in the upper mountain area is similar to runoff time at Poudre Park.

SPECIAL STUDY
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO
TIMING OF MOUNTAIN FLOOD RUNOFF
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

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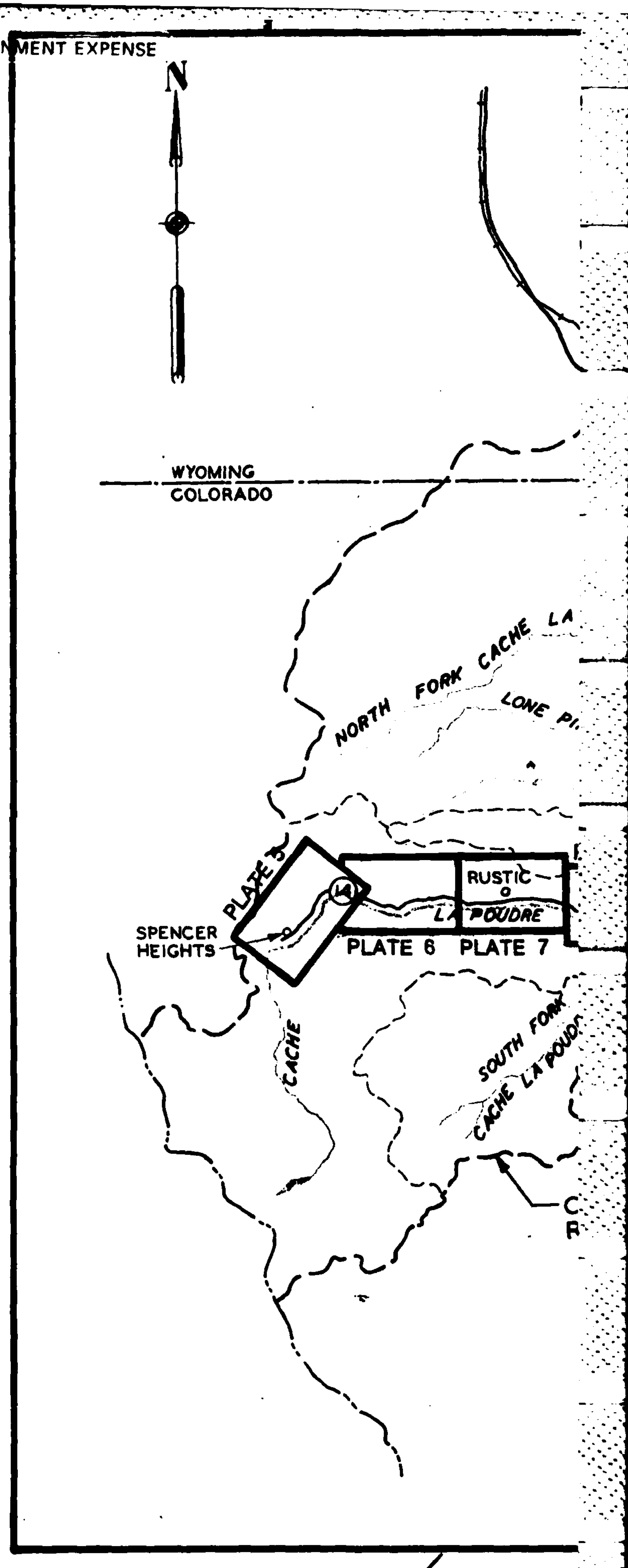
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SOUTH FORK
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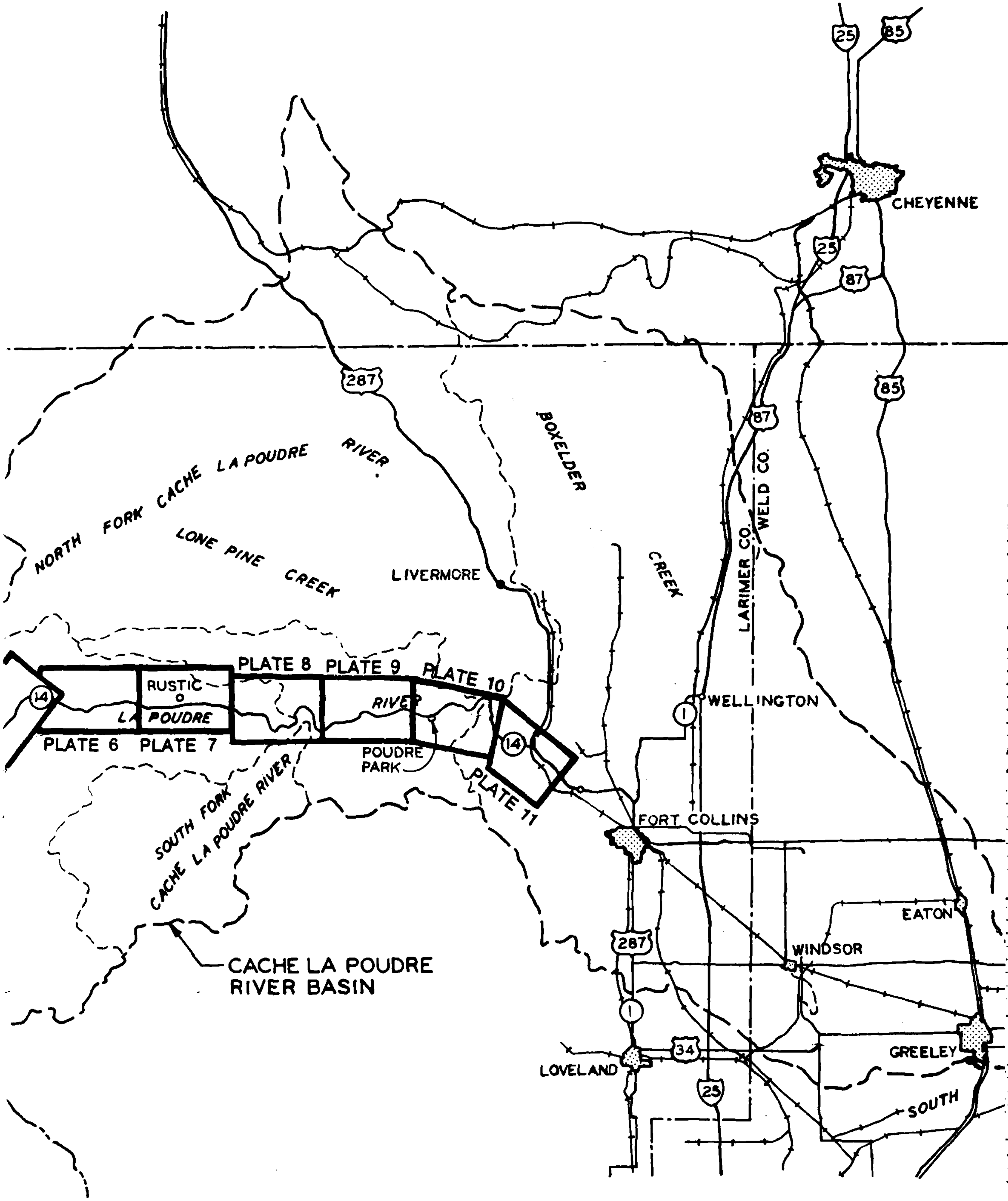
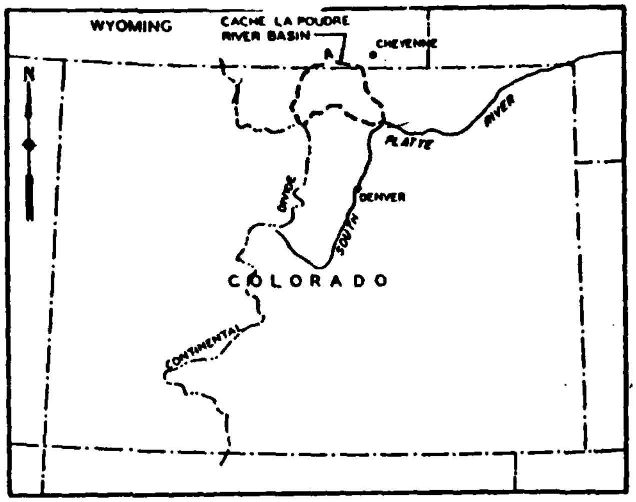


CACHE LA POUDRE RIVER BASIN



LOCATION MAP

SPECIAL STUDY

CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

PLATE
INDEX MAP

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

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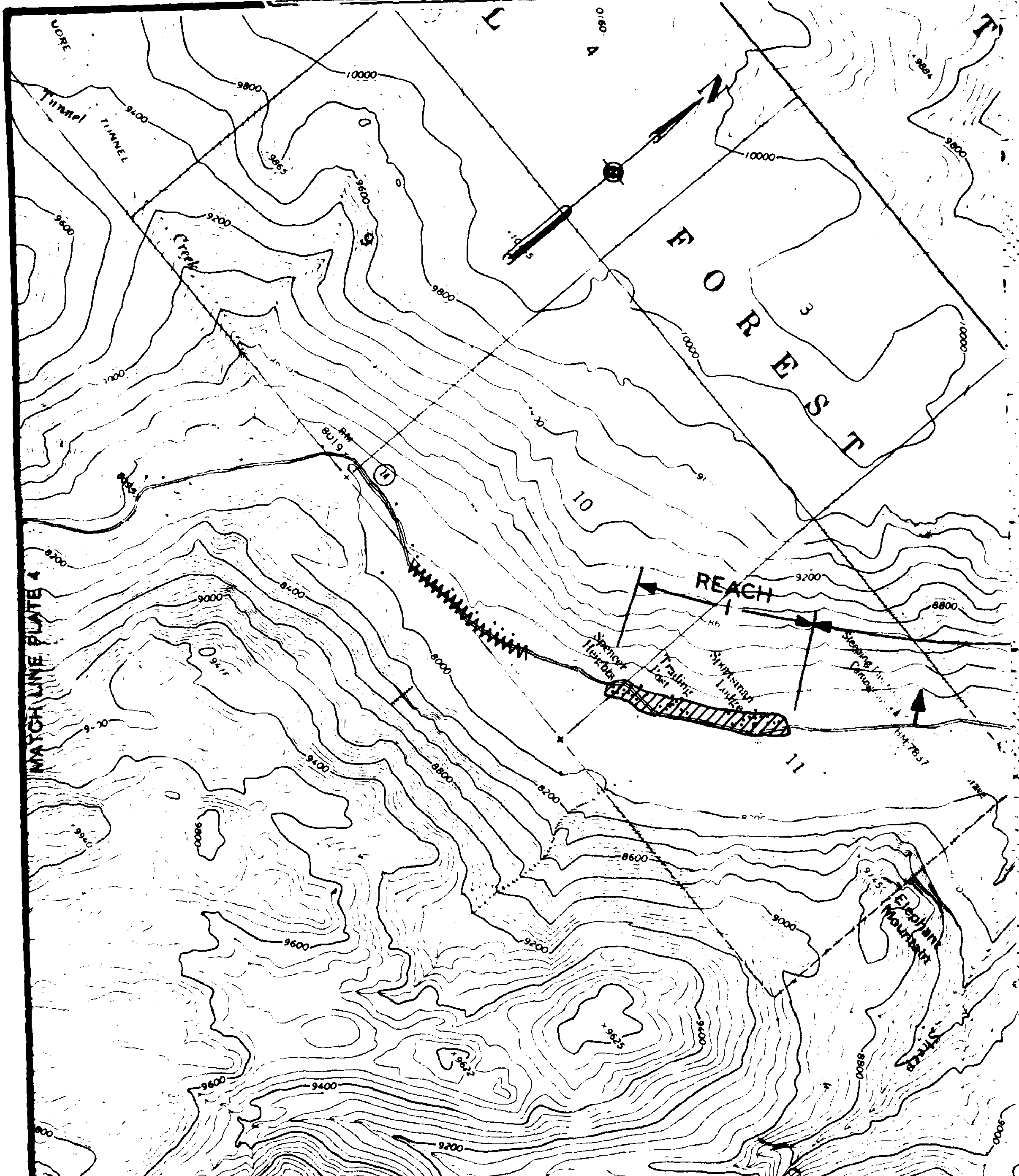
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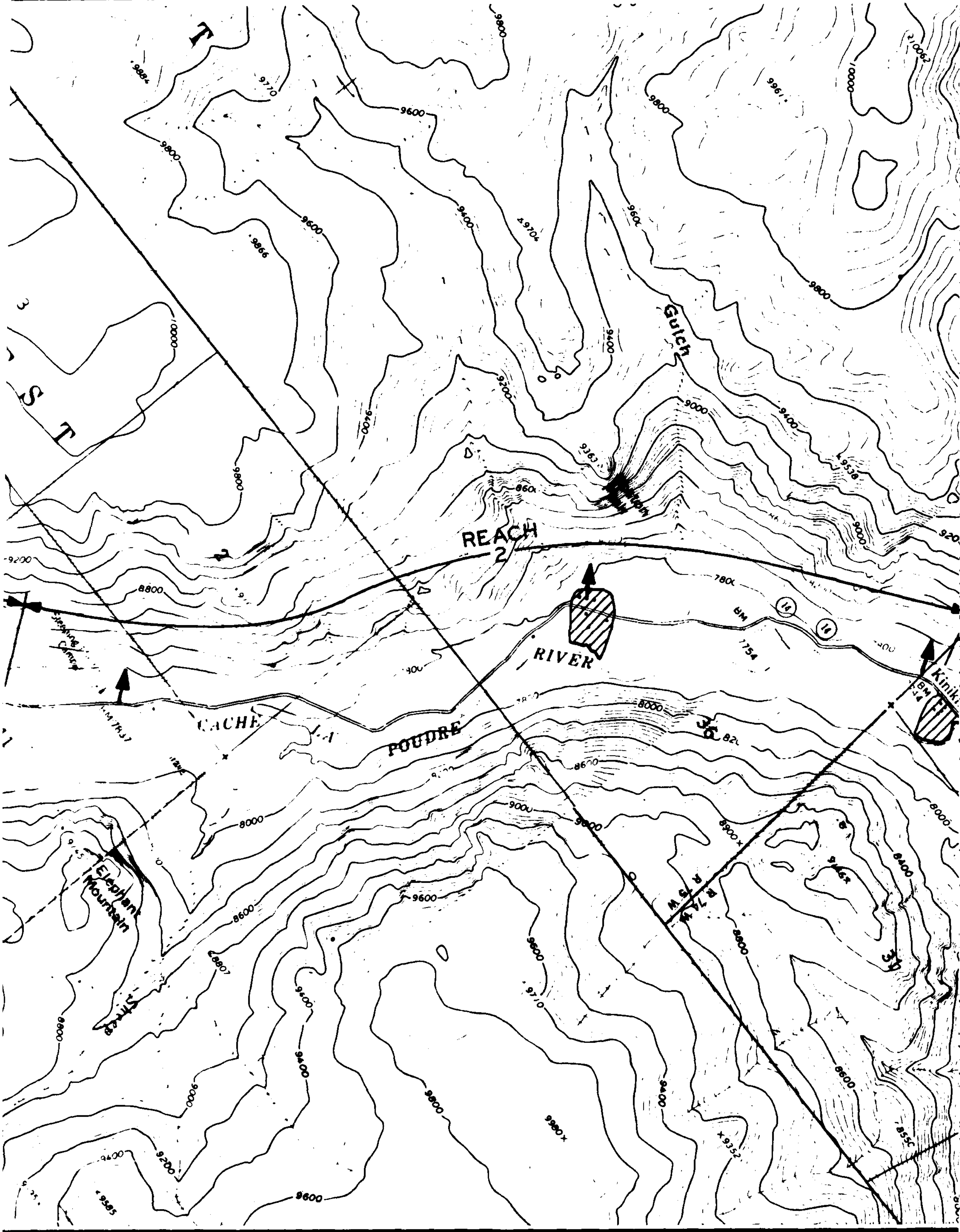
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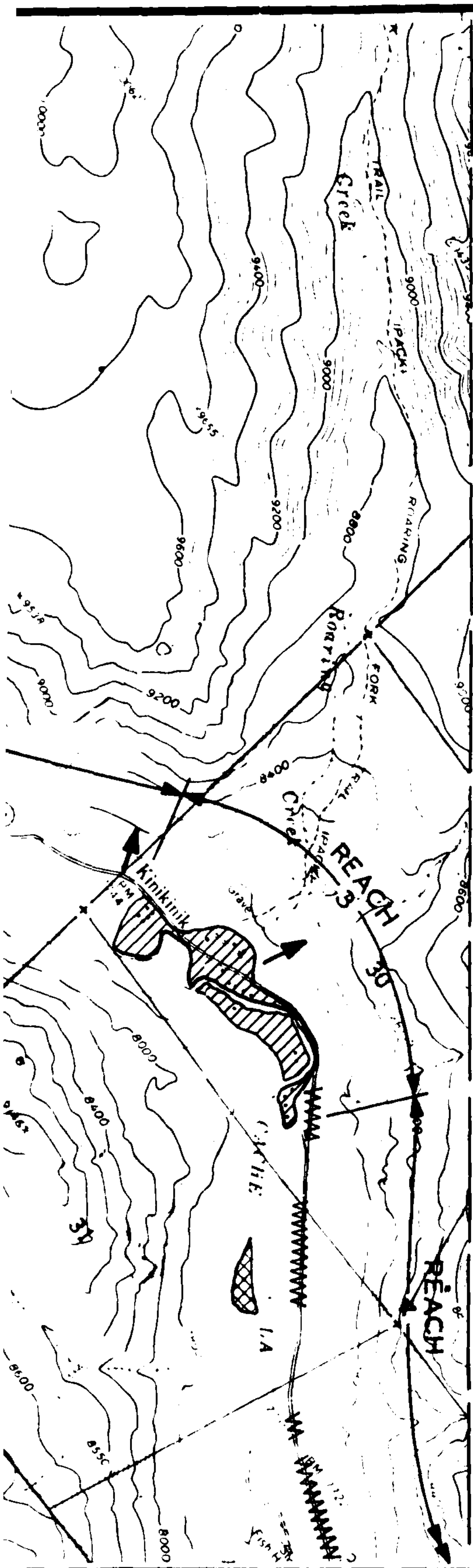
7800
10000



LEGEND:

Concentrations of population subject to flood hazard

Campgrounds

Picnic Areas

Highway Flood Refuge Areas

Typical Walking Evacuation Routes

100-Year Flood Boundary determined by detailed studies

NOTES:

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SCALE IN FEET

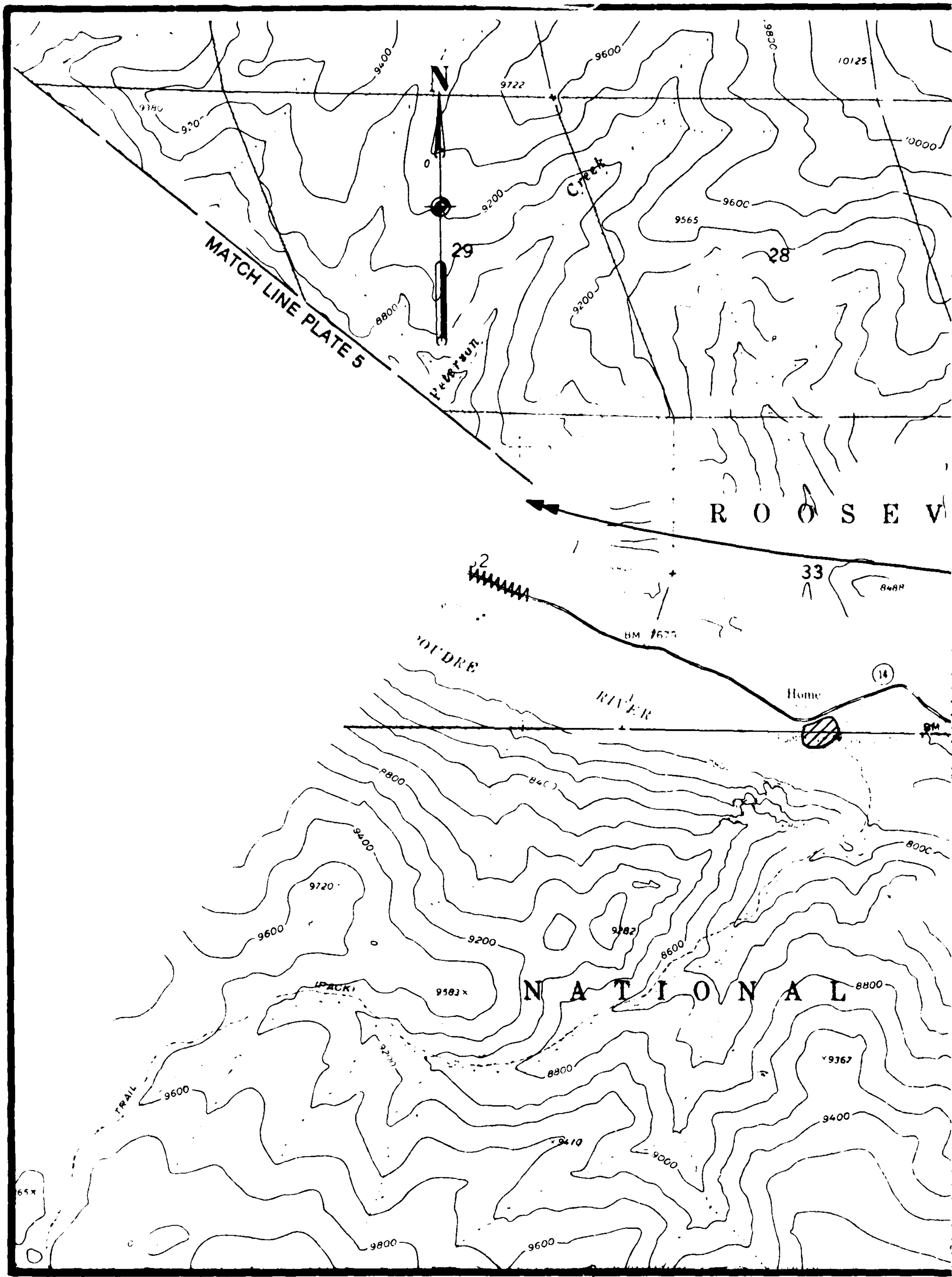
1000 0 1000 2000 3000 4000 5000

SPECIAL STUDY

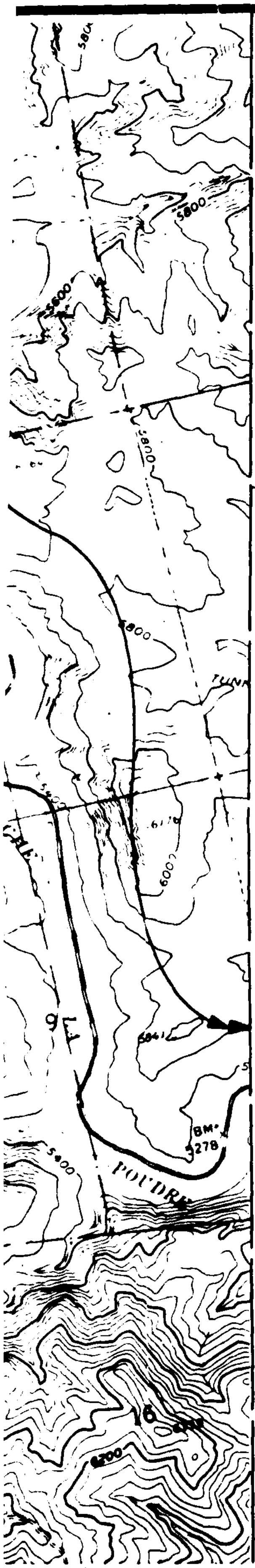
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

FLOOD HAZARD AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981



N
MATCH LINE PLATE 5
Creek
Peterson
29
28
33
ROOSEV
NATIONAL
POUDRE
RIVER
Home
BM
TRAIL
PACK
9400
9600
9722
9200
9800
10125
10000
9565
8800
8488
8400
8000
9720
9282
8600
9583
9367
9410
9000



LEGEND:

- Concentrations of population subject to flood hazard
- Campgrounds
- Picnic Areas
- Highway Flood Refuge Areas
- Typical Walking Evacuation Routes
- 100-Year Flood Boundary determined by detailed studies

NOTES:

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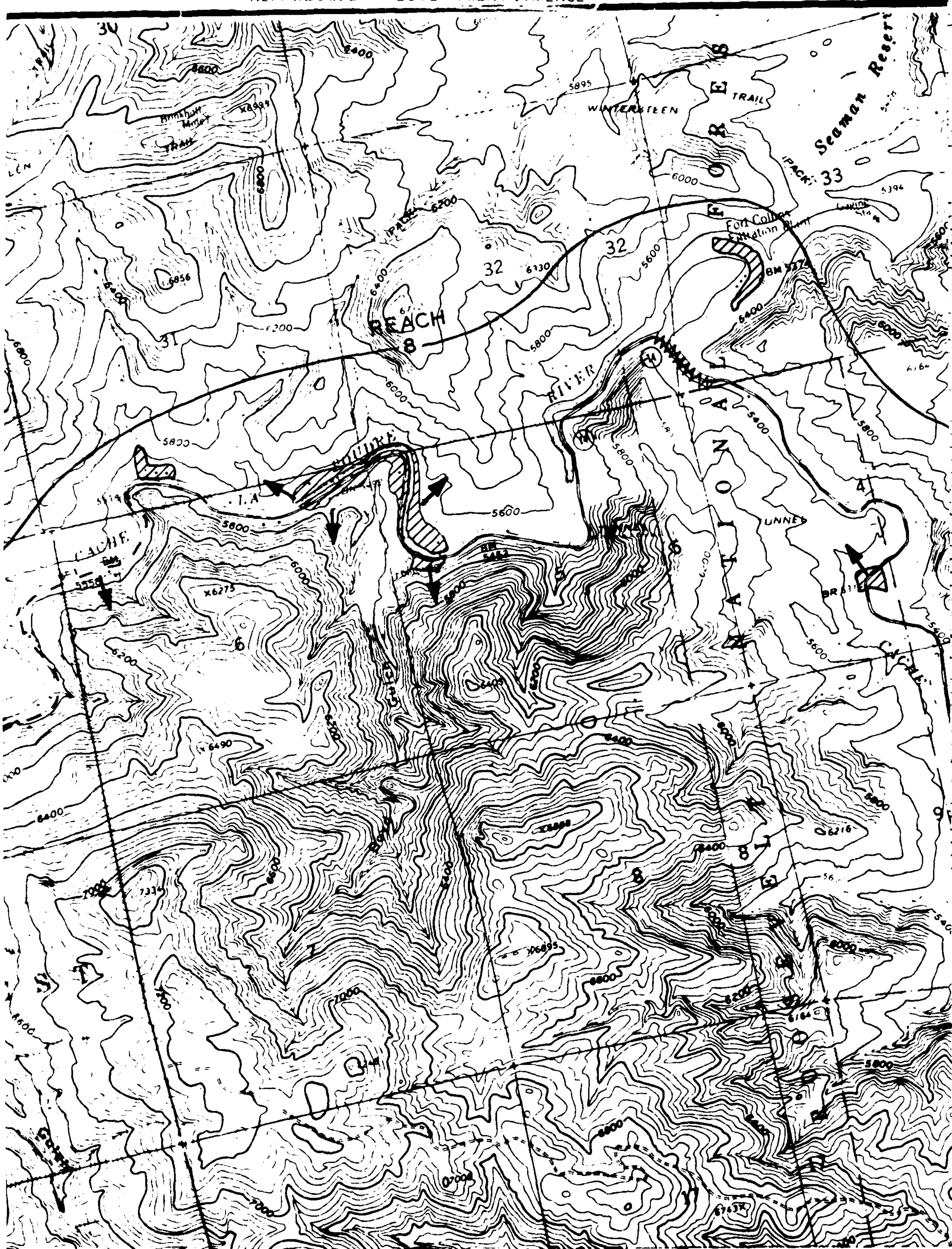
SPECIAL STUDY

CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

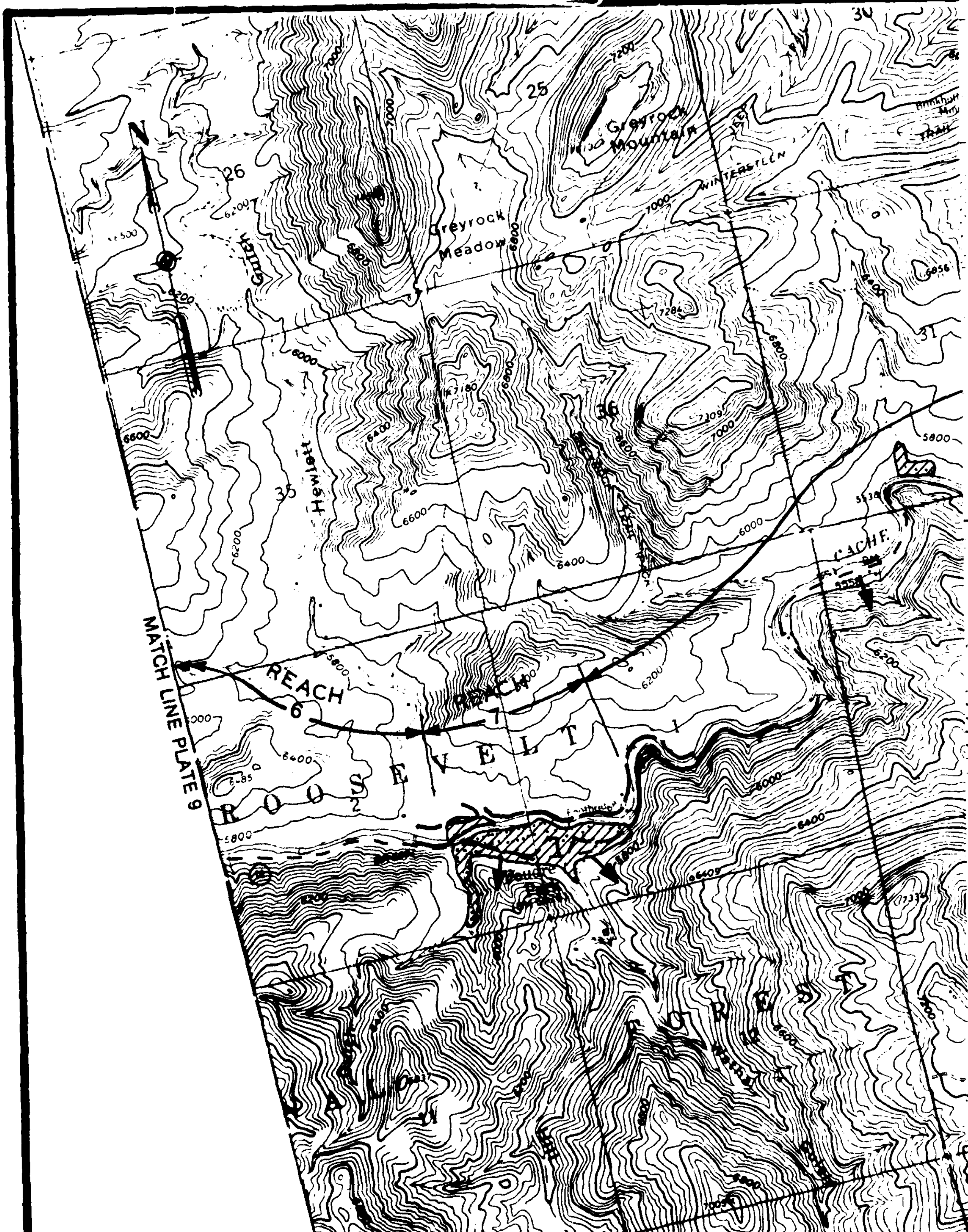
FLOOD HAZARD AREA

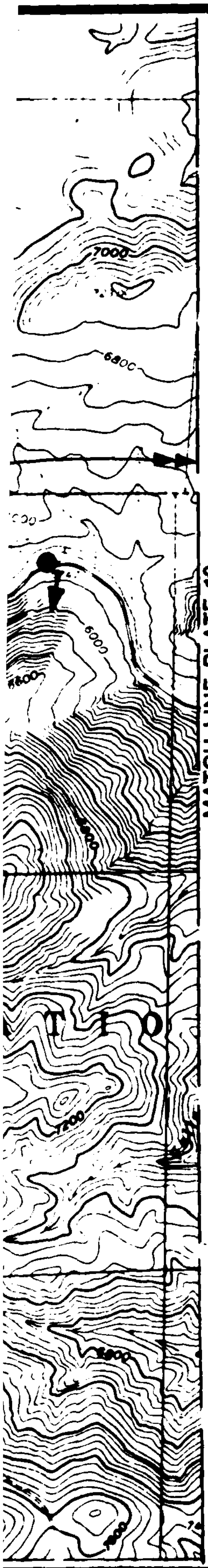
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981


REACH
8
WINTERSTEEN
TRAIL
RIVER
CACHE
5600
5800
6000
6200
6400
32
33

2

REPRODUCED AT GOVERNMENT EXPENSE





LEGEND:

- Concentrations of population subject to flood hazard
- Campgrounds
- Picnic Areas
- Highway Flood Refuge Areas
- Typical Walking Evacuation Routes
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1000 0 1000 2000 3000 4000 5000

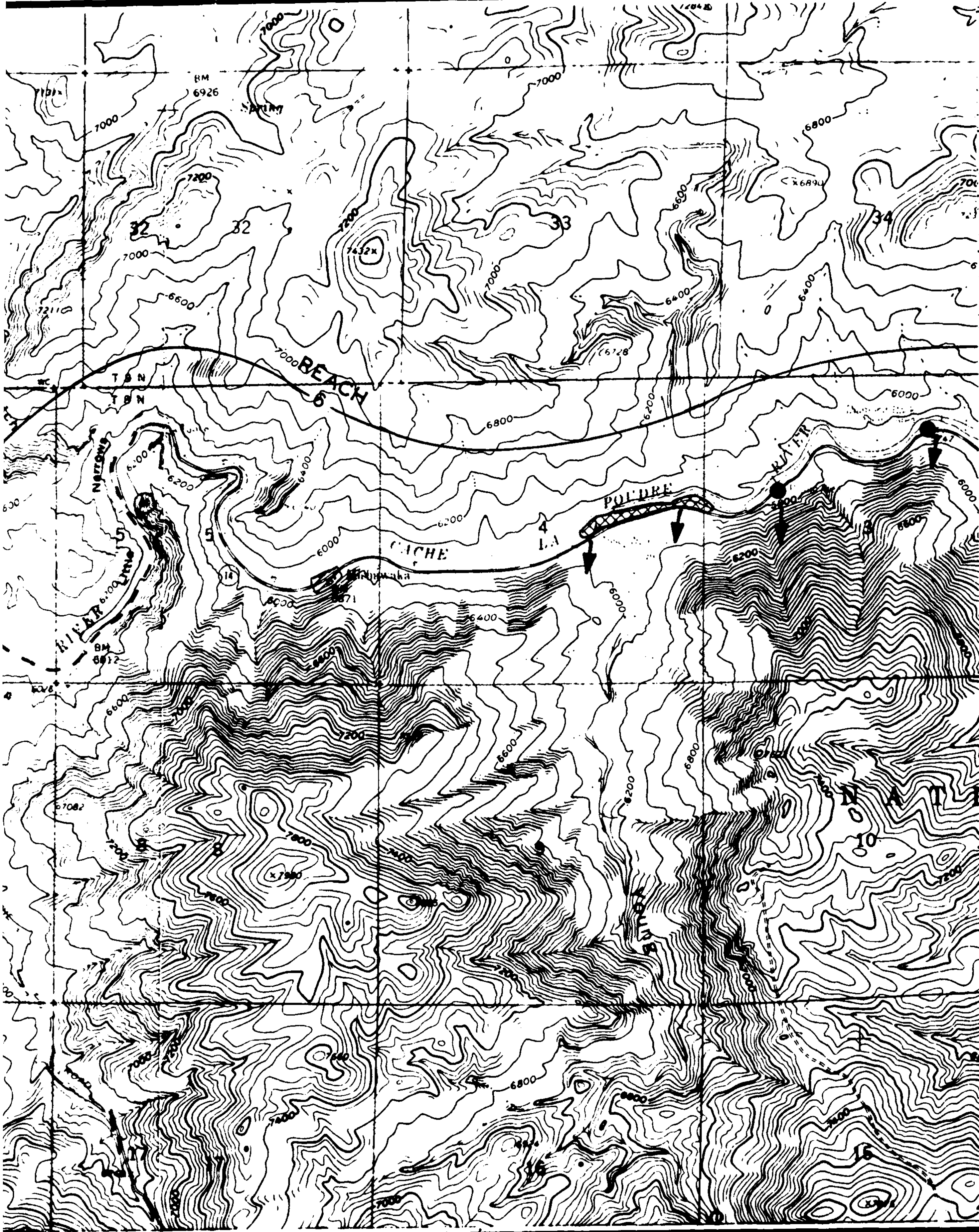
SPECIAL STUDY

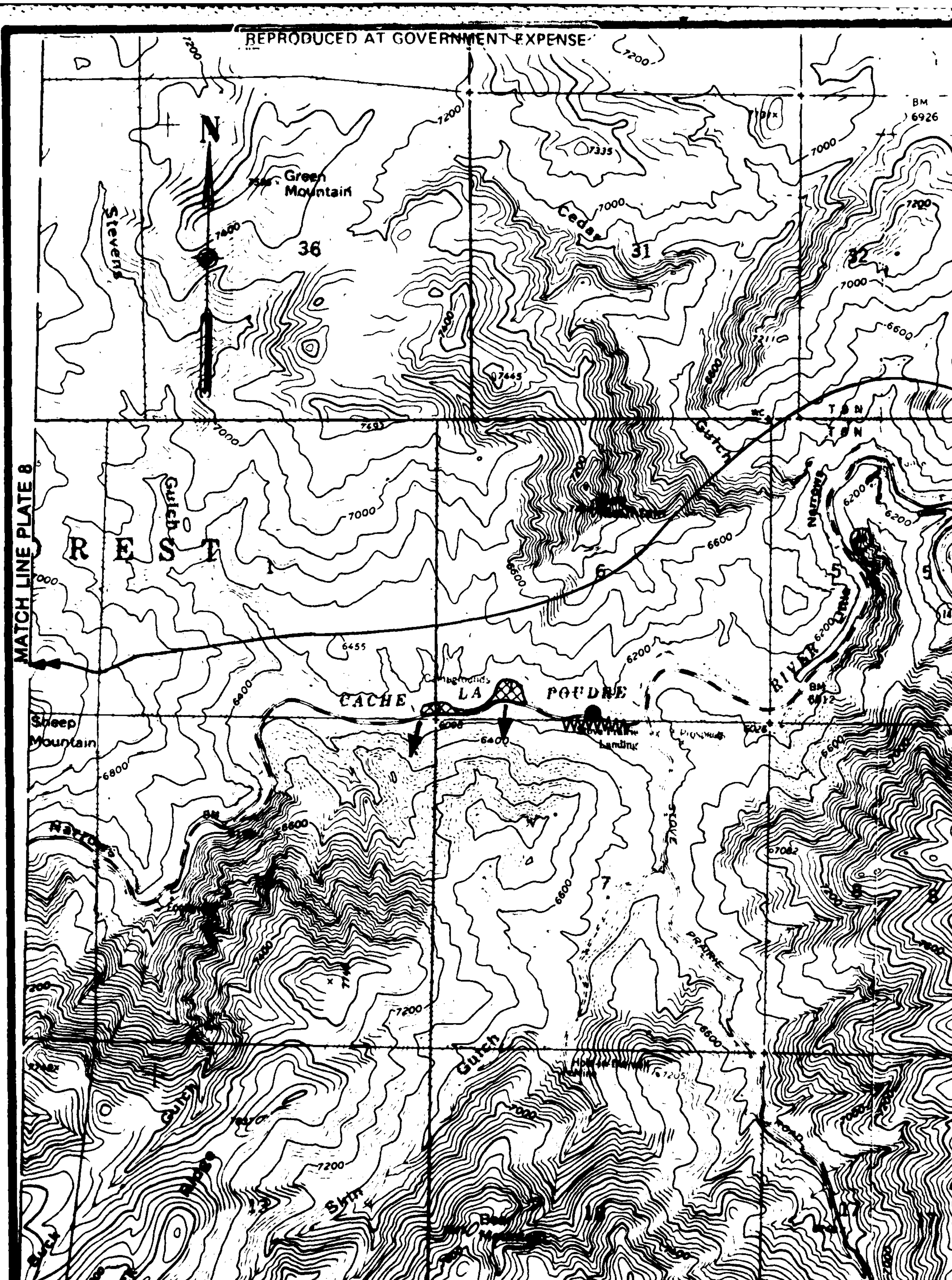
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

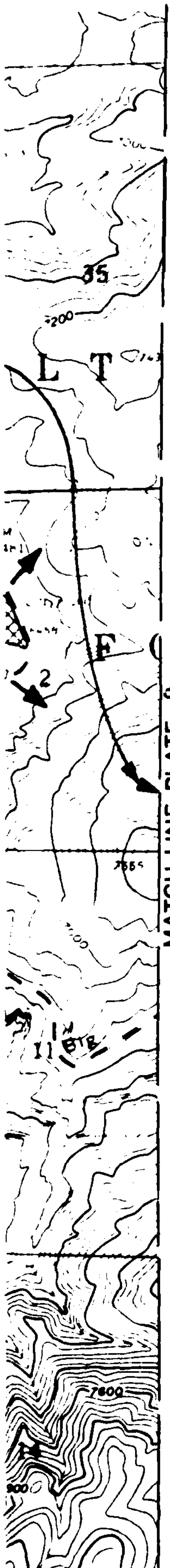
FLOOD HAZARD AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

3


REACH
6
T8N
T8N
BM
6926
Spring
Narrows
Little
RIVER
CACHE
LA
POUDRE
RIVER
Mishawaka
BM
6812
N A T I
32
33
34
5
4
3
8
9
10
16
15


N
Green Mountain
Stevens
Cedar
Gulch
MATCH LINE PLATE 8
R E S T
CACHE LA POUDRE RIVER
Campgrounds
Sheep Mountain
Narrows
Gulch
Ridge
Skin
Bear
36
31
32
6
5
7
8
7200
7000
6600
6400
6200
6800
BM
6926
7335
7465
6455



LEGEND:

Concentrations of population subject to flood hazard

Campgrounds

Picnic Areas

Highway Flood Refuge Areas

Typical Walking Evacuation Routes

100-Year Flood Boundary determined by detailed studies

NOTES:

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SCALE IN FEET

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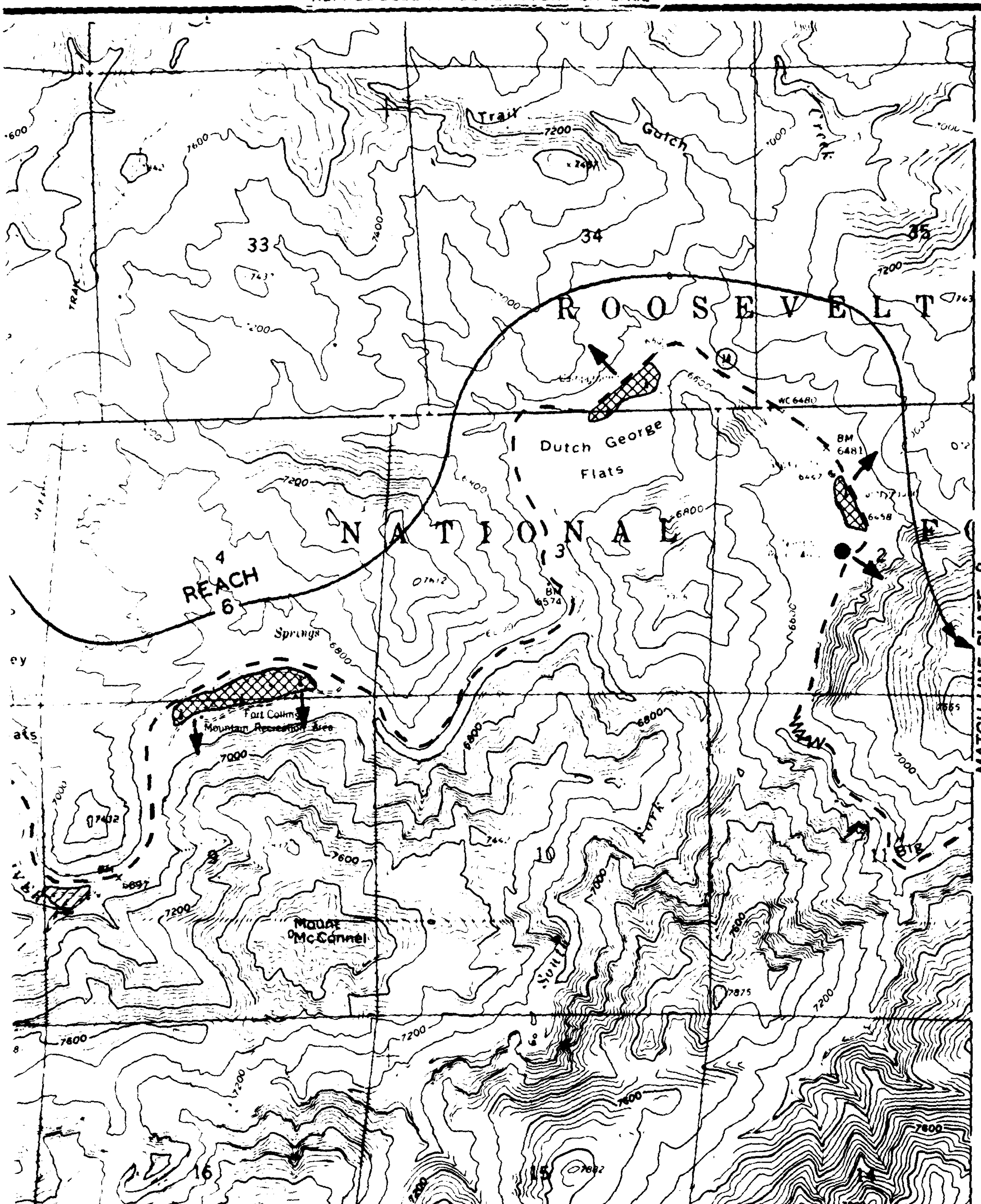
SPECIAL STUDY

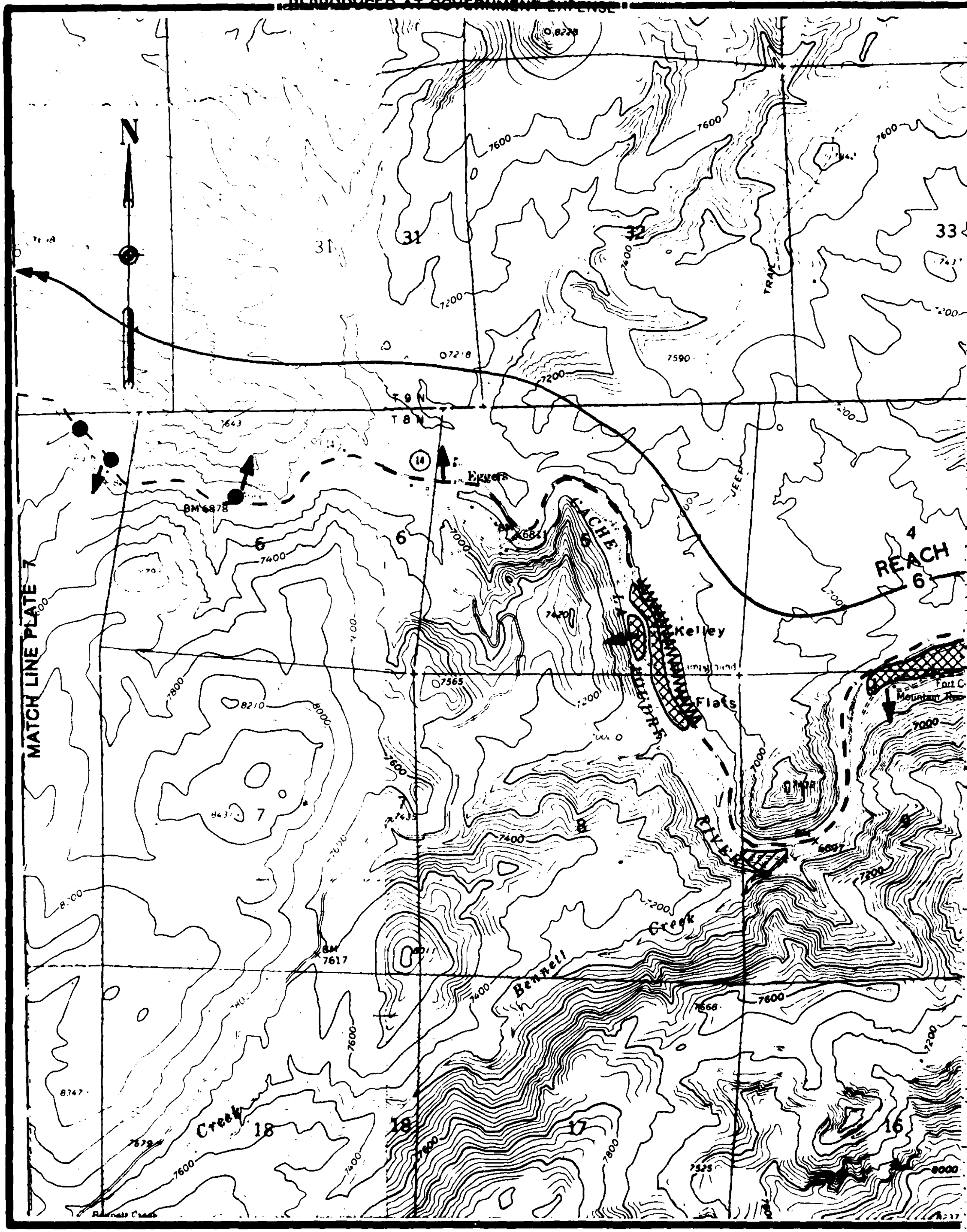
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

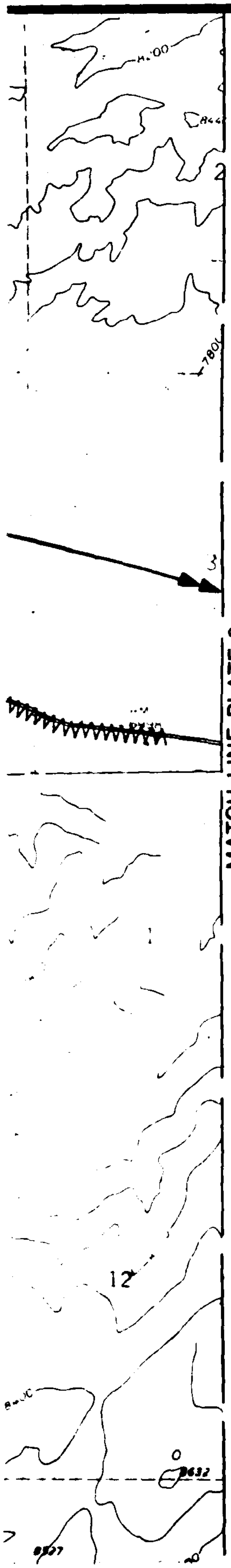
FLOOD HAZARD AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981



Trail
Gulch
33
34
35
ROOSEVELT
NATIONAL
Dutch George
Flats
REACH
6
Springs
Fort Collins
Mountain Recreation Area
Mount
McConnel
BM
6481
MATCH LINE PLATE 9
10
11
15
16


N
MATCH LINE PLATE 7
REACH
4
6
31
32
33
T9N
T8N
BM 6878
Eggers
6
7
8
9
16
17
18
LACHE
Kelley
Flats
RIVER
Creek
Bennett
Creek
7600
7200
7400
7000
7800
8000
8210
7590
7565
BM
7617
7668
7525



LEGEND:

Concentrations of population subject to flood hazard

Campgrounds

Picnic Areas

Highway Flood Refuge Areas

Typical Walking Evacuation Routes

100-Year Flood Boundary determined by detailed studies

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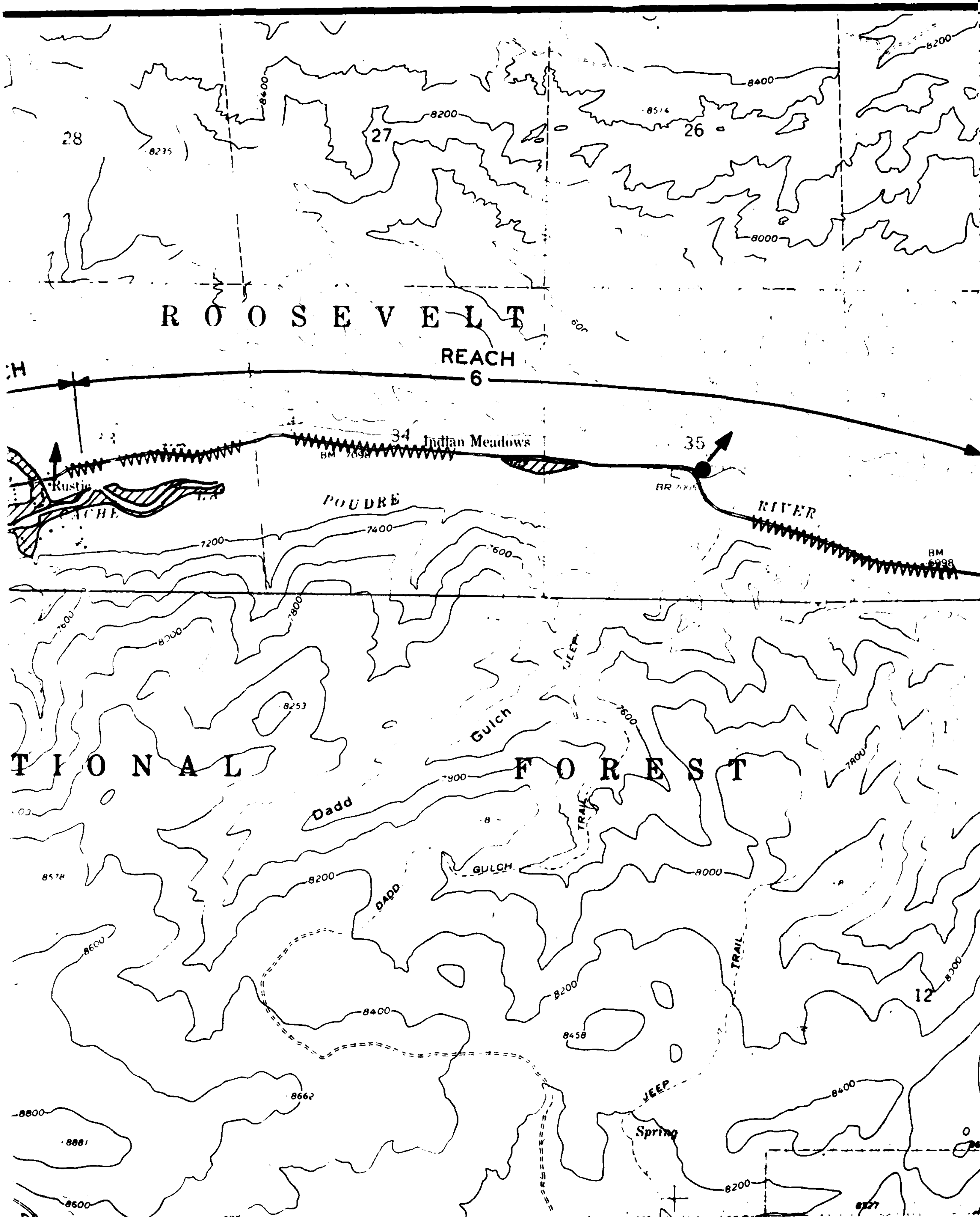
SPECIAL STUDY

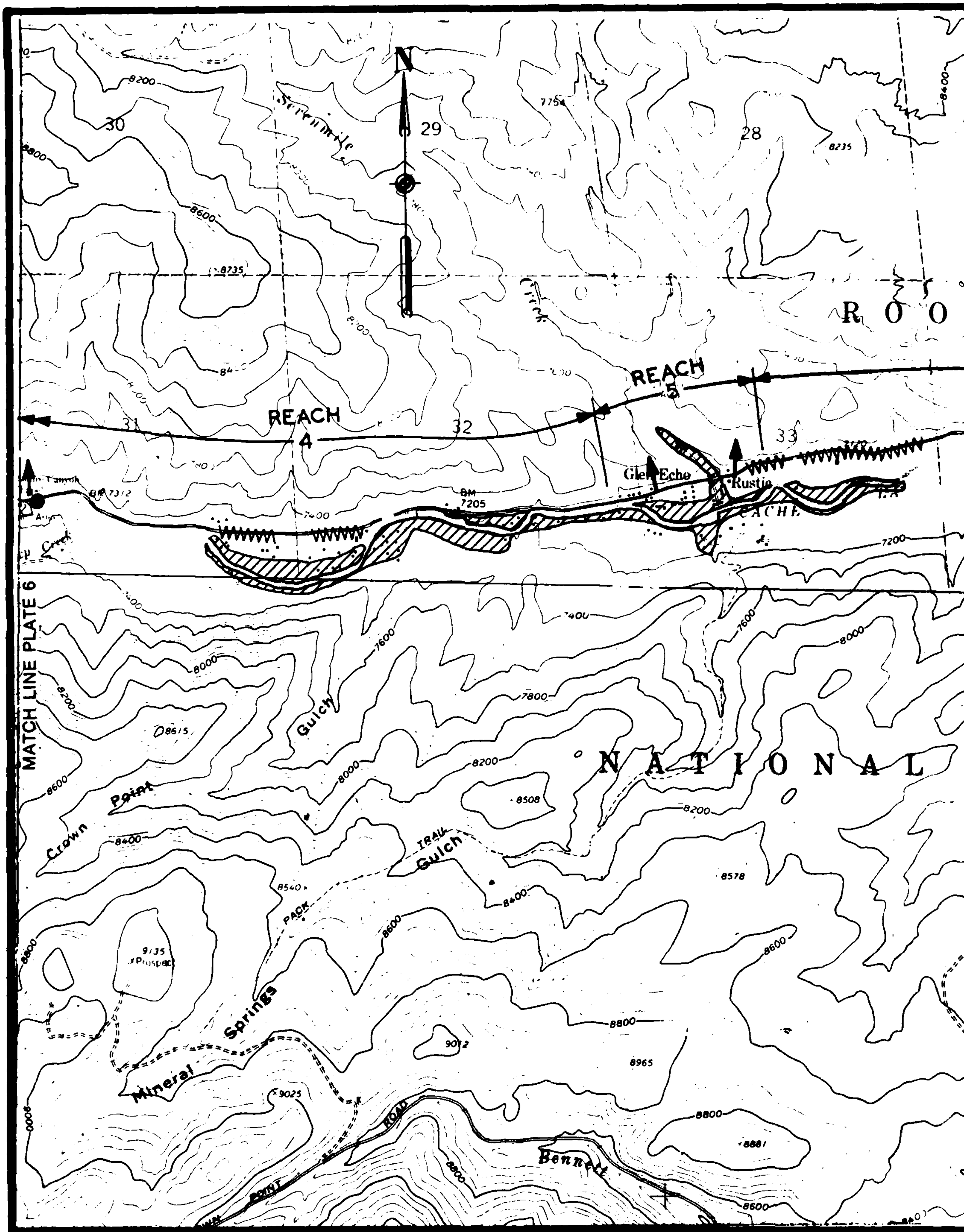
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

FLOOD HAZARD AREA

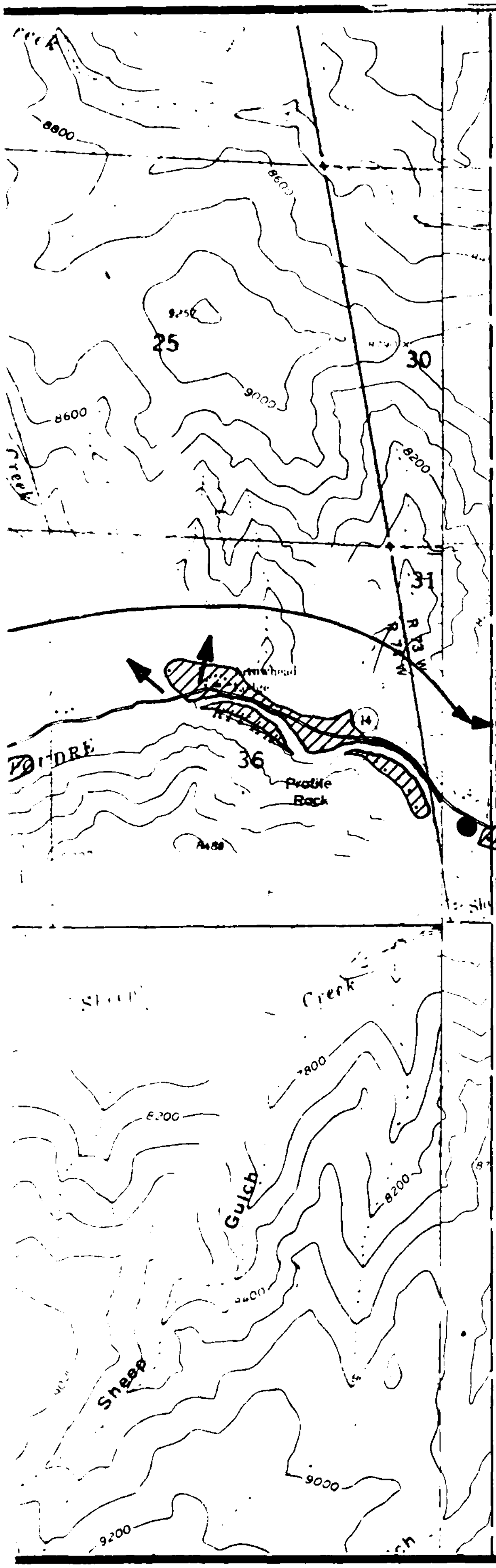
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

3


ROOSEVELT
REACH
6
Indian Meadows
Rustic
POUDRE
RIVER
TIONAL FOREST
Dadd
Gulch
DADD
GULCH
JEEP
TRAIL
Spring
28
27
26
34
35
12
8400
8200
8000
7400
7200
7600
7800
8600
8800
8253
8458
8662
8881
BM 6998



N
29
30
28
31
32
33
REACH
4
REACH
5
ROO
NATIONAL
Glen Echo
Rustic
CACHE
BM 7312
BM
7205
MATCH LINE PLATE 6
Gulch
Crown Point
Gulch
TRAIL
PACK
Mineral Springs
Bennett
ROAD
POINT
8200
8600
8800
8735
8400
8235
7200
7400
7600
7800
8000
8515
8508
8578
8540
9135
Prospect
9012
8965
9025
8881
8600



LEGEND:

- Concentrations of population subject to flood hazard
- Campgrounds
- Picnic Areas
- Highway Flood Refuge Areas
- Typical Walking Evacuation Routes
- 100-Year Flood Boundary determined by detailed studies

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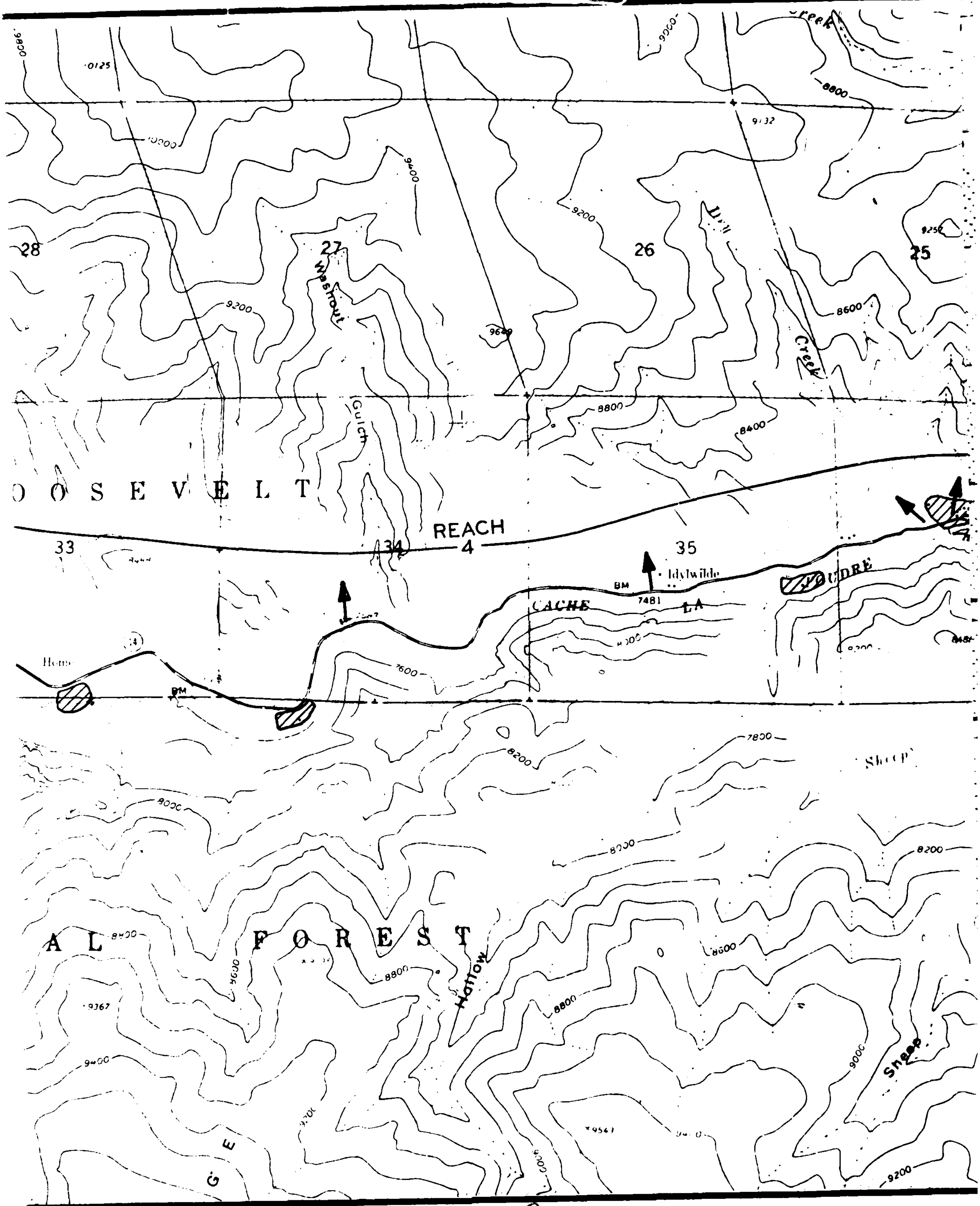
SPECIAL STUDY

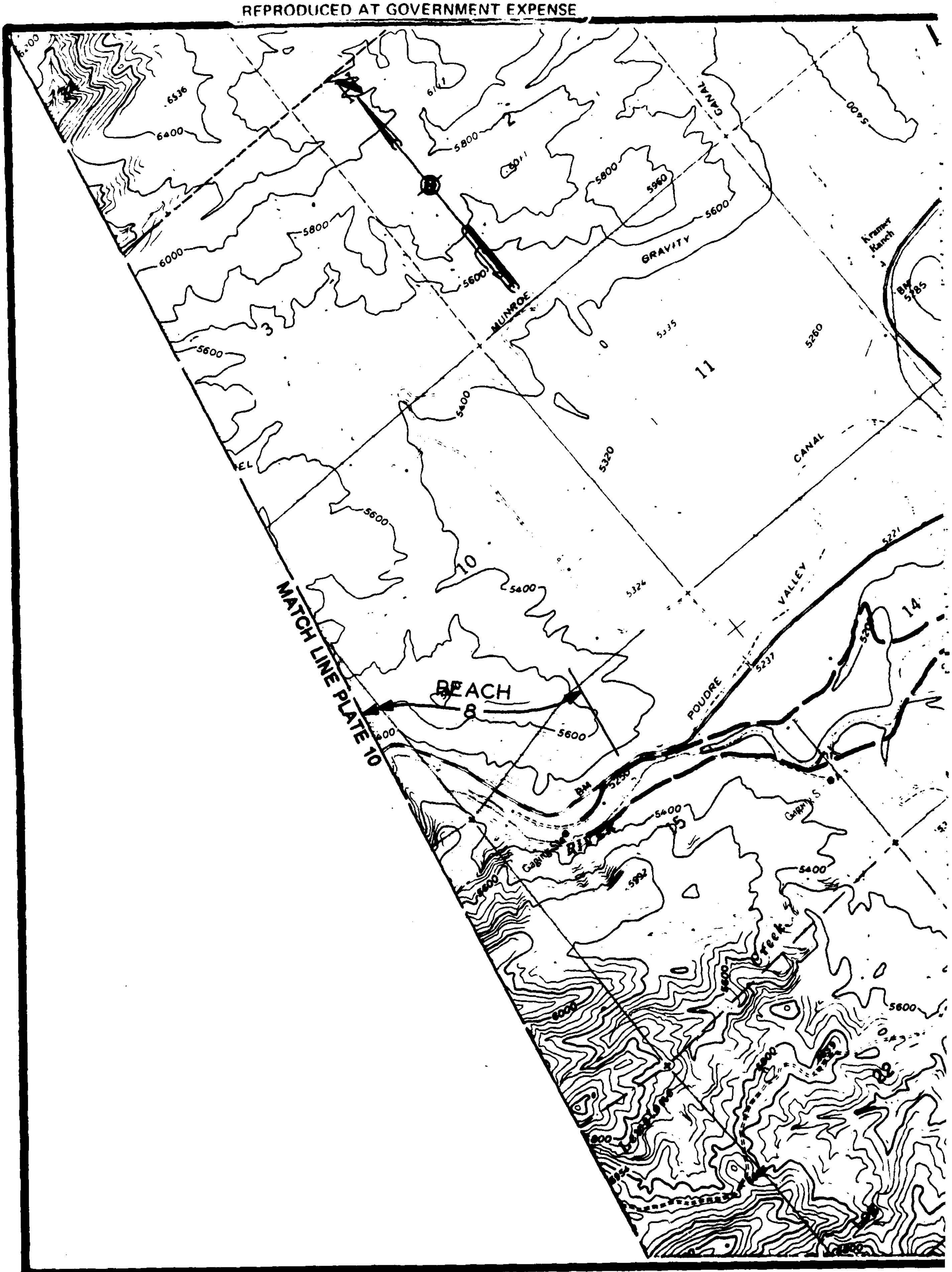
CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

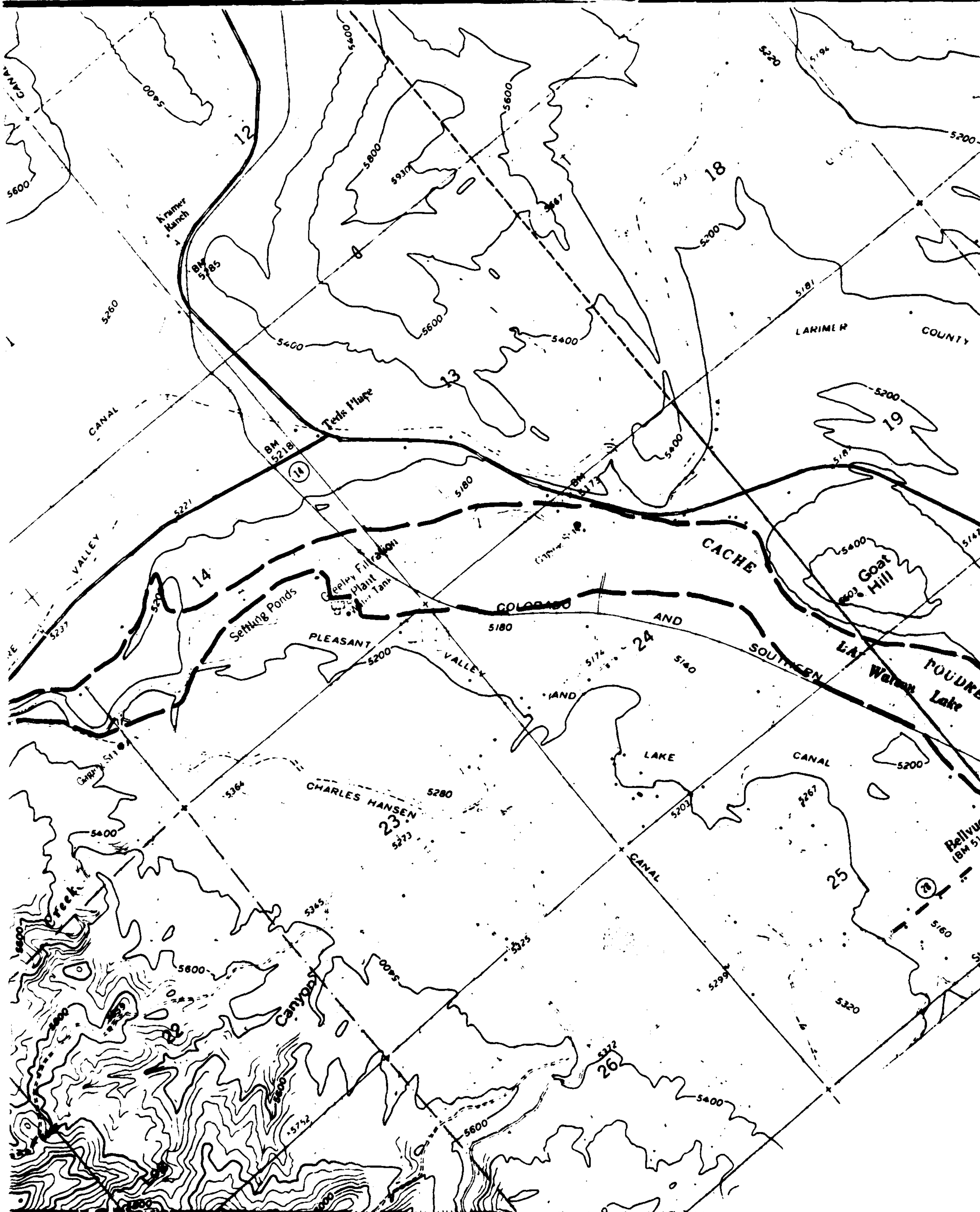
FLOOD HAZARD AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA


28
27
26
25
Washout
Gulch
Creek
9200
9400
9600
8800
8600
8400
9132
9649
OOSEVELT
REACH
4
33
34
35
Idylwilde
BM
7481
CACHE
LA
OUDRE
7600
7800
8200
8000
Sheep
AL
FOREST
Hollow
9367
9000
9200
Sheep

2


MATCH LINE PLATE 10
REACH 8
MUNROE
GRAVITY
CANAL
POUDRE
VALLEY
CANAL
RIVER
Kramer Ranch
3
2
10
11
14
15
22
6536
6400
6000
5800
5600
5400
5960
5335
5260
5320
5324
5221
5237
5992


Kramer Ranch
BM 5285
5260
CANAL
VALLEY
Teds Place
BM 5218
5221
5237
14
12
13
18
19
24
23
25
26
22
5600
5400
5800
5200
5180
5160
LARIMER COUNTY
CACHE
LA POUDRE
COLORADO AND SOUTHERN
Goat Hill
Watson Lake
Settling Ponds
Greeley Filtration Plant
PLEASANT VALLEY AND LAKE CANAL
CHARLES HANSEN CANAL
5280
5364
5365
5325
5299
5320
5267
5203
Bellvue
Canyon
Creek

LEGEND:

Concentrations of population subject to flood hazard

Campgrounds

Picnic Areas

WWWWW Highway Flood Refuge Areas

Typical Walking Evacuation Routes

100-Year Flood Boundary determined by detailed studies

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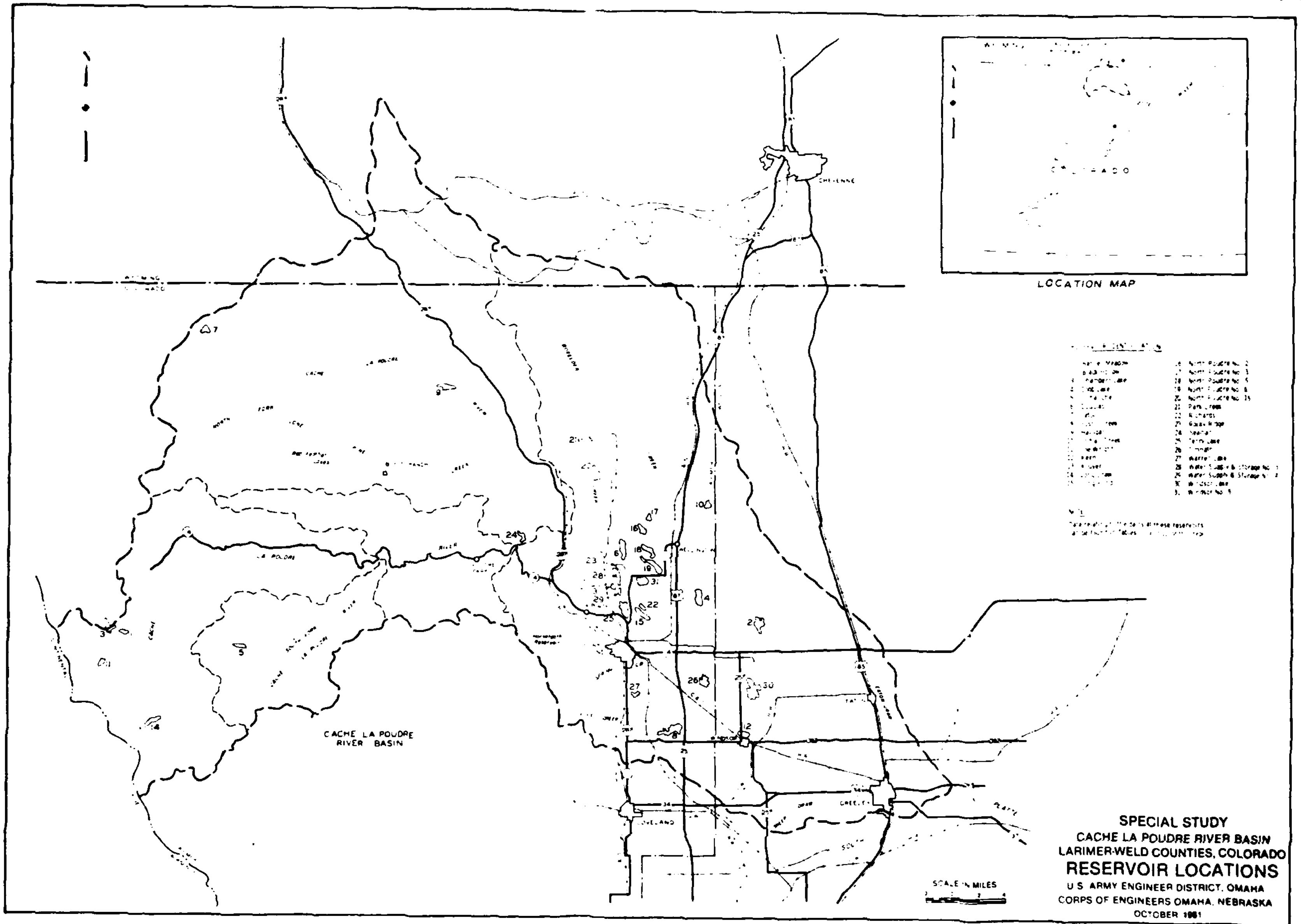
1000 0 1000 2000 3000 4000 5000

SPECIAL STUDY

CACHE LA POUDRE RIVER BASIN
LARIMER-WELD COUNTIES, COLORADO

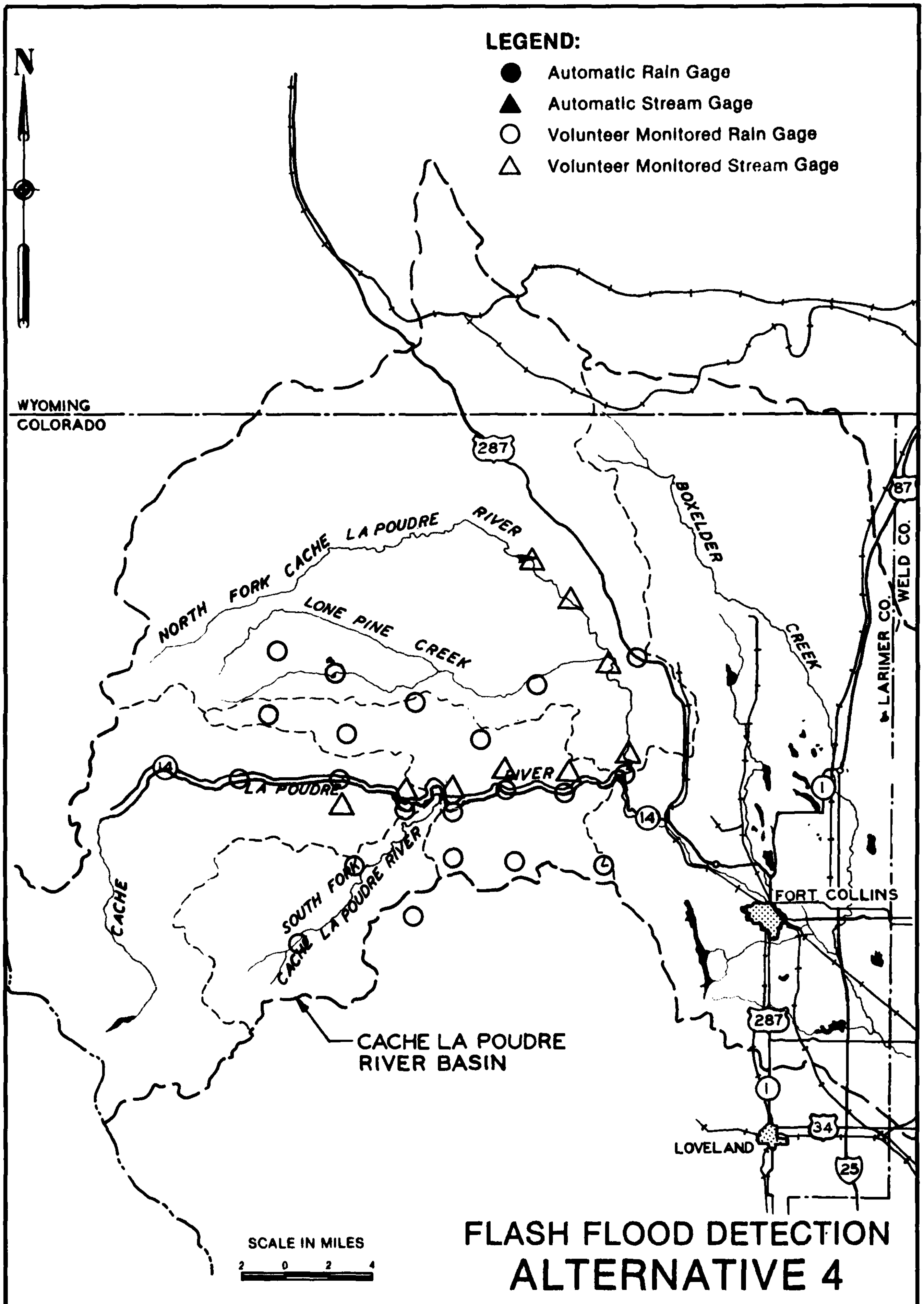
FLOOD HAZARD AREA

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
OCTOBER 1981

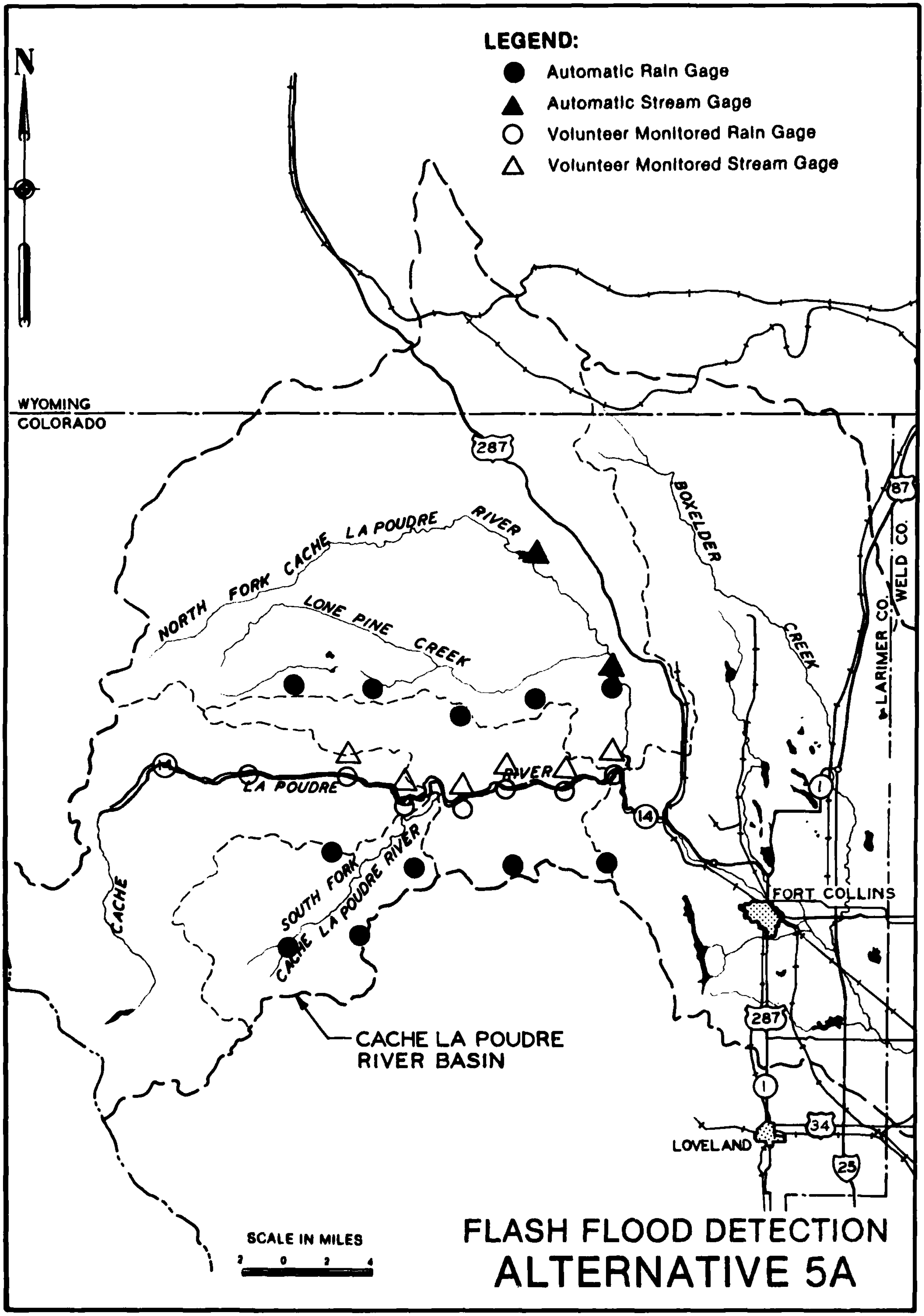


VOLUME I

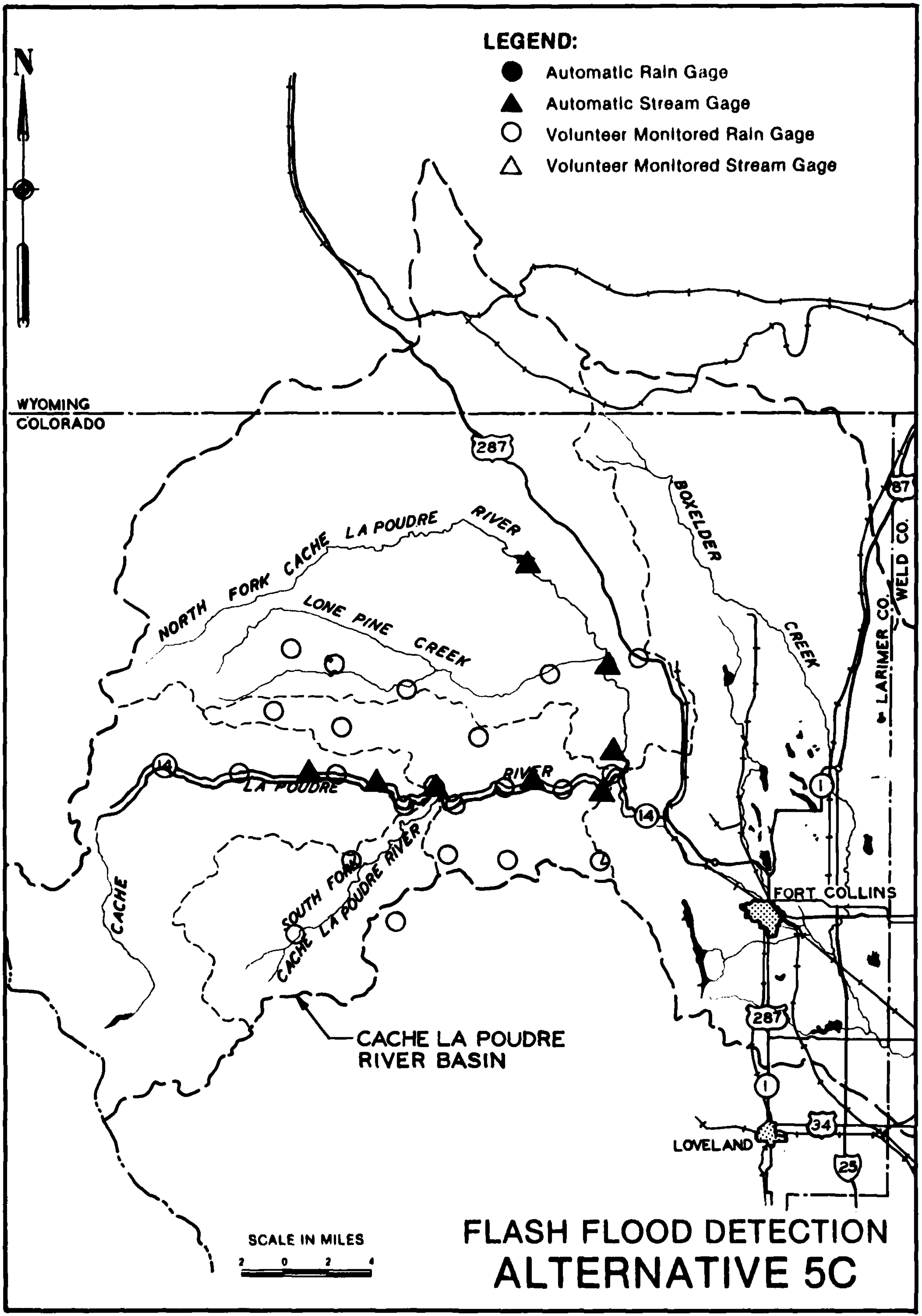
PLATE 12



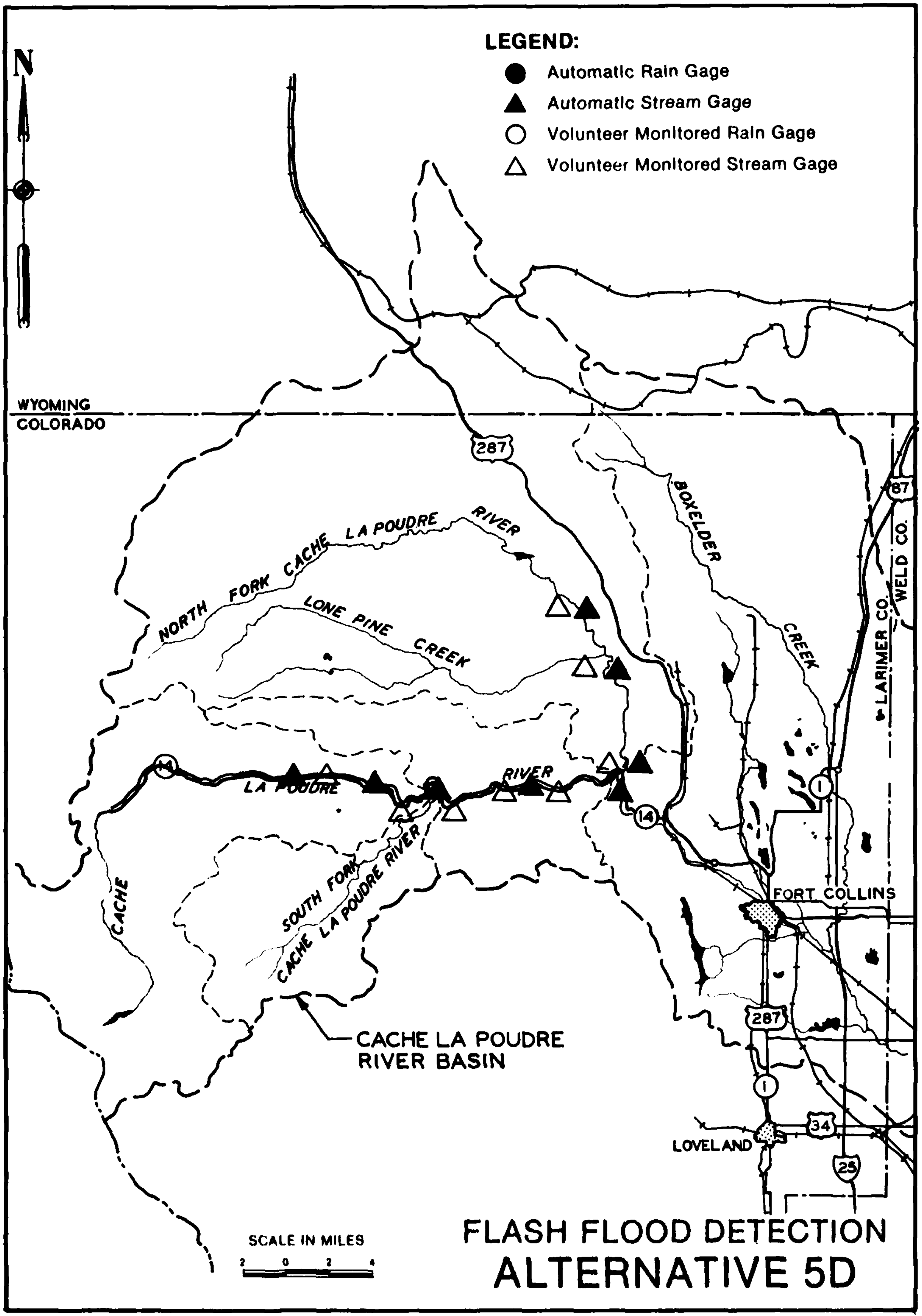
FLASH FLOOD DETECTION
ALTERNATIVE 4

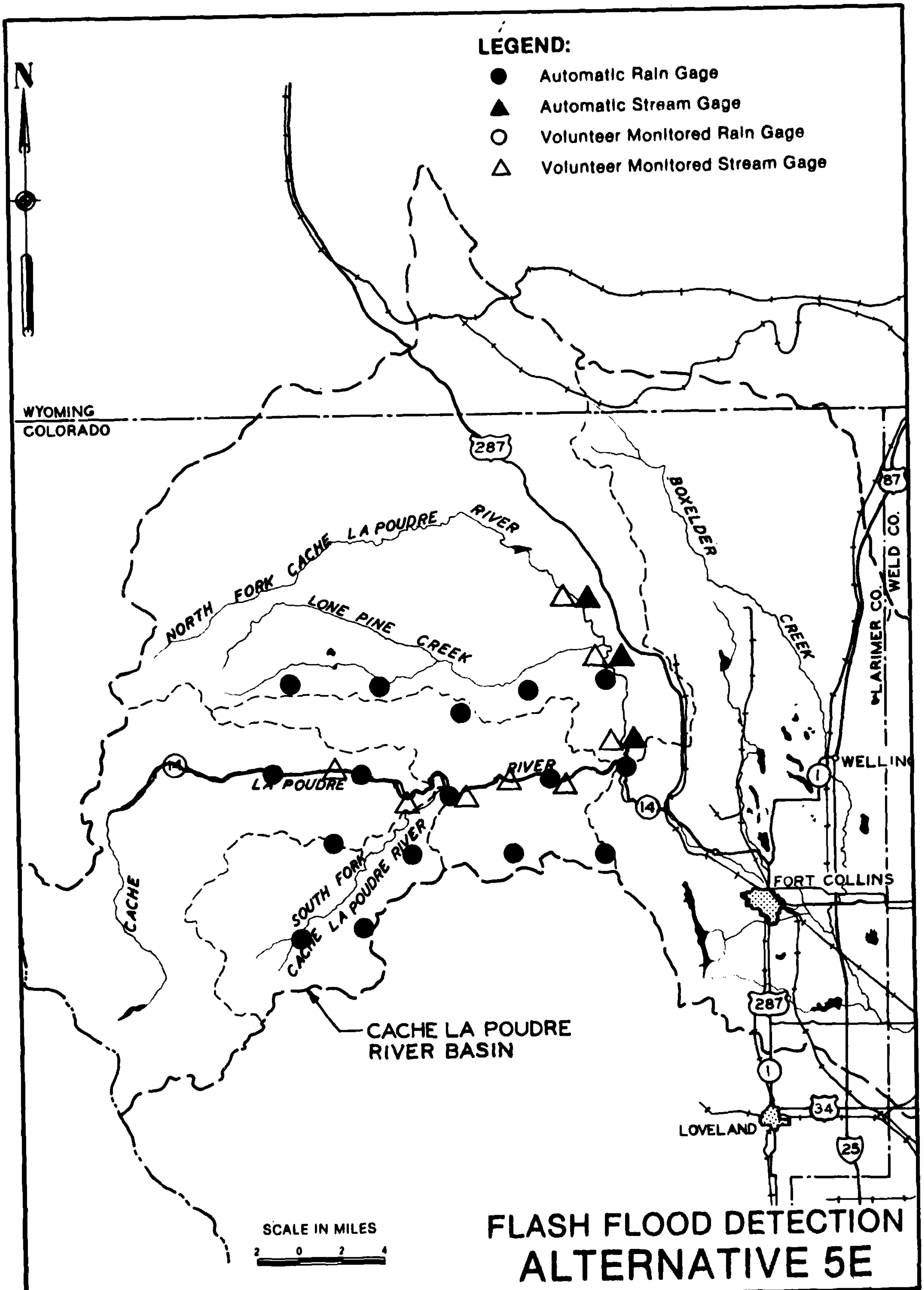


FLASH FLOOD DETECTION
ALTERNATIVE 5A

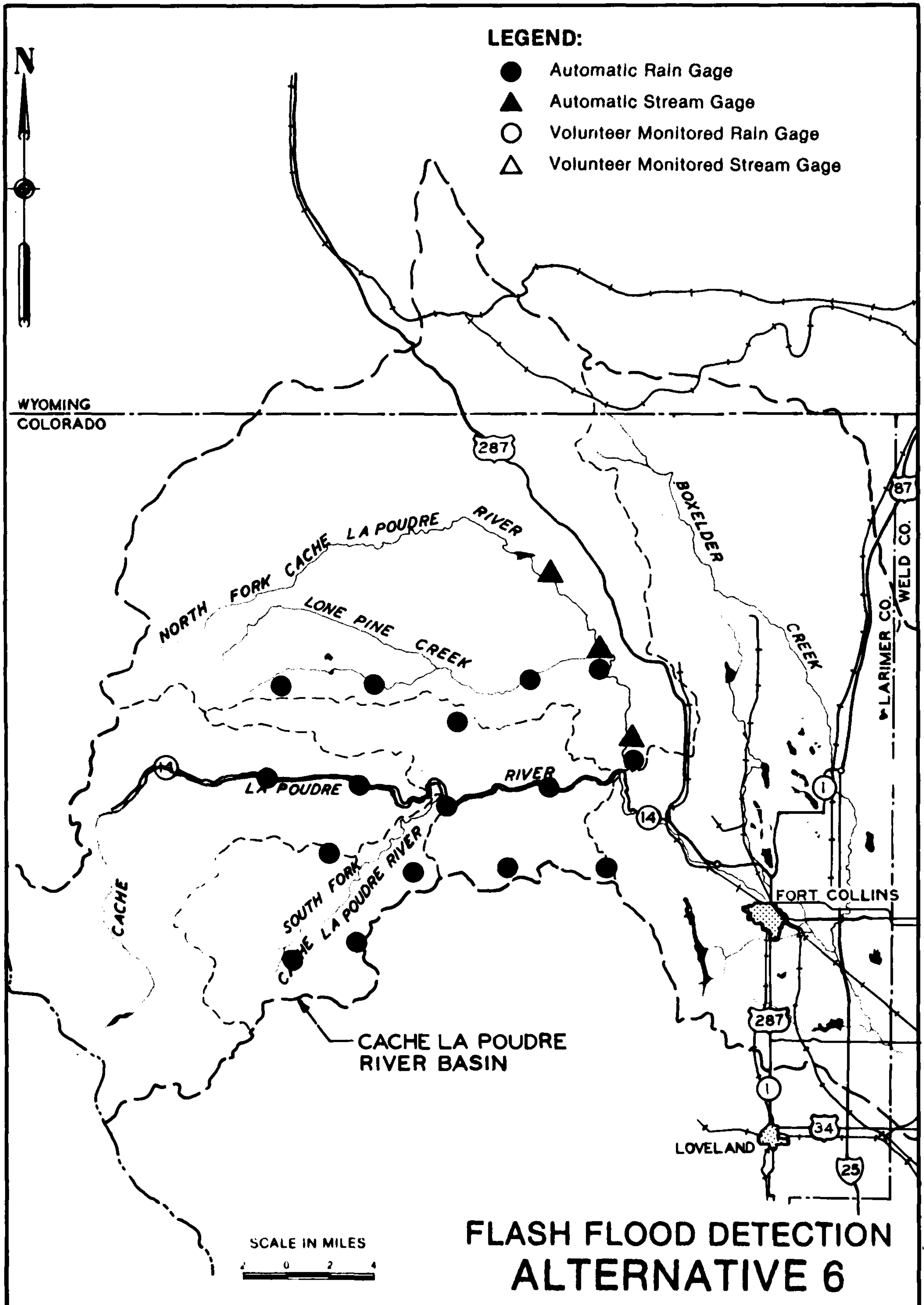


FLASH FLOOD DETECTION
ALTERNATIVE 5C


LEGEND:
Automatic Rain Gage
Automatic Stream Gage
Volunteer Monitored Rain Gage
Volunteer Monitored Stream Gage
N
WYOMING
COLORADO
287
BOXELDER
CREEK
NORTH FORK CACHE LA POUDRE RIVER
LONE PINE CREEK
87
WELD CO.
LARIMER CO.
LA POUDRE
RIVER
14
1
SOUTH FORK
CACHE LA POUDRE RIVER
CACHE
FORT COLLINS
CACHE LA POUDRE
RIVER BASIN
34
LOVELAND
25
SCALE IN MILES
2 0 2 4
FLASH FLOOD DETECTION
ALTERNATIVE 5D



FLASH FLOOD DETECTION
ALTERNATIVE 5E



FLASH FLOOD DETECTION ALTERNATIVE 6

END

FILMED

5-85

DTIC